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Abstract

Historically, Thailand had a deep connection with wood as a construction material. Thai vernacular architecture utilized this material in almost all of its building elements and it was the most common form of residential buildings. In present day however, concrete has become the most common material in construction, while timber construction has faded into obscurity. Concrete is one of the leading unsustainable materials in construction, comprising up to 5 percent of the global CO2 emissions and this thesis will aim to address the problem of over utilizing this material in Thailand.

Timber is a material that perform better in topic of sustainability and will be the main focus of this thesis. This thesis will explore the possibility of contributing to the development of Thai timber construction with the goal of creating positive environmental impact in the global scale. This contribution will focus on the role of architect, while maximizing its positive impact. The development of "Thai contemporary timber construction system" will be the method for this contribution. This proposed system will aim to facilitate the process of building contemporary timber construction for Thai designers and builders. The utilization of this system should create a good quality building and maintaining strength of timber construction, while making the process of design and building assemble less challenging. This is done through investigation, development and demonstration of "Thai contemporary timber construction system" and evaluation process.

According to the evaluation process, "Thai contemporary timber construction system" has shown the potential of timber construction in the context of Thailand. With the utilization of imported lumber in conjunction with relevant knowledge, both local and foreign, timber construction can be competitive with concrete construction. This competitiveness came from its aesthetic, low carbon emission and end of life value that timber has in comparison to its higher construction cost.

Preface

Sustainable development is the emergent topic that has seen rapid rising in attention for the past few decades. Within the topic of sustainable development, environmental issues have been widely discussed and published more and more in the global scale. The attention to environmental awareness has been brought up and cemented by increasing negative feedback in our environment, which can be evidently perceived all over the world. Massive loss of biodiversity, rising sea level, extreme temperature and drought are some of the few problems that we have encountered frequently. These events have been identified to be cause by our own actions by environmentalists and scientists. In all of the negative feedbacks from the environment, climate change is one of, if not, our most concerned problem. Since, this problem can affect the whole ecosystem in a fundamental way, it can change our livelihood and threaten the survival of many species including human. The problem of climate change is extremely complex and has been building up over a long period of time. Its impact is also scaling up exponentially and need radical change in our society to solve this problem. Radical change, which is not easy to achieve, requires contribution from members of our society in all levels.

Built environment has established its importance in our modern life and has large scale impact on the environment including its effect on global climate. It is responsible for more than 30% of global CO_2 emission and contributes severely to the problem of climate change. Buildings affect our environment before it has been built, throughout its life and have continuing effect after they are demolished. CO_2 emission is released to the atmosphere when the production of construction material started. Transport of construction material also emits CO_2 emission in lesser amount. During its function, it continues to release CO_2 emission through daily energy consumption and through replacement and maintenance of building components. At the end of its life, it takes energy to dismantle, and in the case of some construction material, continue to release CO_2 emission in to the atmosphere. Currently, the usage phase emits the most CO_2 in all of a building lifespan; follow closely by the production phase. However, this trend is expected to change in the future, due to the increasing efficiency of energy production. This means that, the choice of construction material will have increased environmental impact in the future. This trend will make material choice more meaningful for the development of sustainable built environment

In all of construction material, concrete in particular has contributed the most to the problem of CO_2 emission in our built environment. More than 5% of global CO_2 emission is currently cause by the use of concrete alone. It has moderate embodied carbon but required large amount of material mass to be usable. Concrete also needs to be reinforced with steel for it to perform effectively as load bearing components. Our current end of life solution for concrete is also very limited. Concrete structural member is not reusable and breaking down as small gravel is its only option for recycle. This means that, the quality of the material is highly deteriorated after its first usage. Moreover, the source of concrete material is not renewable, given enough time material scarcity will have tremendous effect on its availability and feasibility. It is apparent from its attribute that the amount of concrete we currently used does not fit in the concept of sustainable built environment.

Bio-based material for construction, especially wood, has recently been in the spotlight for sustainable building material. Timber has seen widespread uses in vernacular architecture in various part of the world. In many countries, wood has transitioned and established its place in contemporary architecture, while preserving the practice of building vernacular architecture from timber. Most of these countries are developed nations; i.e. Nordic countries, Germany, Switzerland and Japan. However, there are still many developing countries that failed to successfully developed and utilized wood as construction material. Even though, developed countries is currently has higher amount of overall CO_2 emission per capita than developed countries, the urban growth rate in developing countries is significantly higher. This means that, a significant amount of CO_2 emission is still to be emits in to our atmosphere by the process of urban development in developing countries and potentially escalates the problem of climate change.

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fig 1. Wooden House in Thailand - photo : Viriyaroj B.

I. Introduction

Historically, Thailand had a deep connection with wood as a construction material. Thai vernacular architecture utilized this material in almost all of its building elements and it was the most common form of residential buildings. In present day however, concrete has become the most common material in construction, while timber construction has faded into obscurity. In the year 2015, cement production in Thailand reached 35 million metric tons and became the 15th largest global cement producer[1]. Thai construction industry has adapted its whole supply chain to concrete construction, utilizing eighty percent of their produced cement domestically. This development covers the entire construction process, from material production to skills and knowledge of building designers and construction workers.

With small demand for construction grade wood, there is no incentive to invest in the large-scale production of this material. As a result, its price became too high to be competing with other industrialized materials. Currently, in Thailand the price for one of the cheapest construction grade timber species "Shorea obtusa" is around 28.000 baht (800 euro) per cubic meter[2]. This is 10 times the price of concrete with the same mass. In addition, mistrusts in the quality of wooden houses are widely common among the Thais. Deformity, durability, termite attacks and decays are the common concern associated with using wood in Thai buildings. These negative perceptions towards timber construction can be less relevant with the use of good quality timber in the hand of skilled carpenters and knowledgeable designers. However, all of these resources are currently not common in the context of Thailand. Lacks of demand for timber buildings is exceptionally important in this situation. There is no incentive for them to invest in timber construction practice, since the financial benefit from practicing in timber construction are limited by this lack of demand. Without opportunities for builders and designers to practice their skill in timber construction, they have fewer chances to become experienced in this craft. As a result, the number of experienced practitioners in timber construction is dwindling. This in turn, effect the quality of contemporary timber construction making it less appealing for Thai audiences.

Nonetheless, timber construction is not without its merit. Thai vernacular timber building or "Ruen Thai" is revered for its climate adaptability. Aesthetic quality of local timbers in this type of architecture is highly prized, both visually and textually. Rare high-quality wooden furniture is often used to show the status and wealth of its owner, confirming aesthetic values of wood in the eyes of the Thais. Craftsmanship in timber construction also holds its own value in Thai context. "Ruen Thai" is recognized for its level of craftsmanship and implicit knowledge, especially among architects. This adds poetic quality to its already romanticized images. Despite, all the qualities wooden buildings can provide, they are inconsequential when the price different between concrete buildings and timber buildings are too high and skilled practitioners are too rare.

As an architect from Thailand, I have the opportunity to address the problem of unsustainable material usage in Thailand. This thesis will explore the possibility of contributing to the development of Thai timber construction with the goal of creating positive environmental impact in the global scale. This contribution will focus on the role of architect, while maximizing its positive impact. The development of "Thai contemporary timber construction system" will be the method for this contribution. This proposed system will aim to facilitate the process of building contemporary timber construction for Thai designers and builders. The utilization of this system should create a good quality building and maintaining strength of timber construction, while making the process of design and building assemble less challenging.

1. En.wikipedia.org. (2018). List of countries by cement production. [online] Available at: https://en.wikipedia.org/wiki/List_of_countries_by_cement_production [Accessed 15 Mar. 2018].
2. Siammasterwood.com. (2019). ไม้เต็ง. [online] Available at: http://www.siammasterwood.com/ไม้เต็ง.html [Accessed 27 Aug. 2019].

fig 2. Thai Vernacular Architecture

fig 3. Bangkok Skyline

fig 2. Thai Vernacular Architecture - source : https://www.muangboranmuseum.com/landmark/the-thai-hamlet-from-the-central-plains/
fig 3. Bangkok Skyline - source : https://www.lonelyplanet.com/articles/bangkoks-best-views-top-vantage-points-to-admire-the-thai-capital

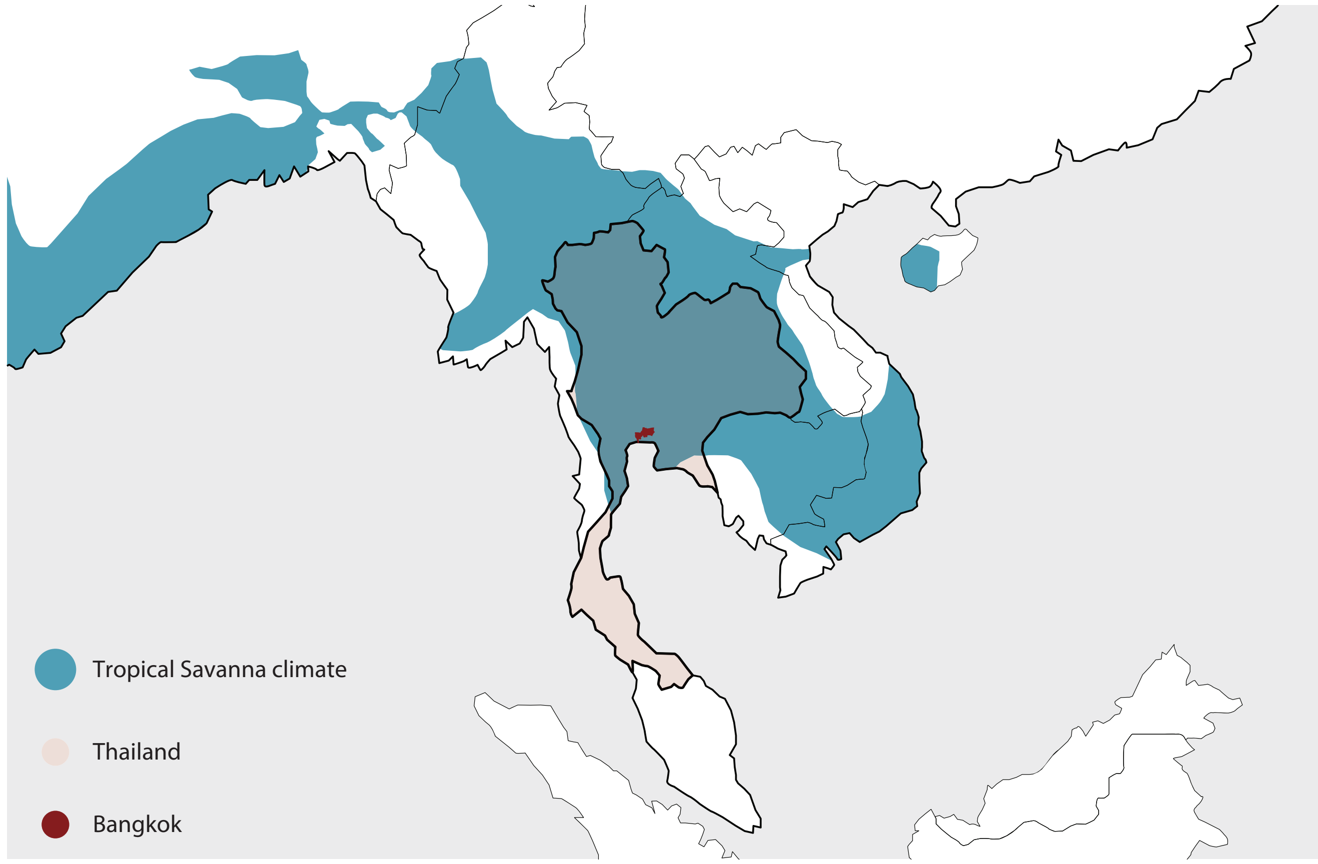
fig 4. Bangkok Street - photo : Viriyaroj B.

II. Framework

Creating the framework is crucial to the development of "Thai contemporary timber construction system", especially in its early stages. For an architectural project, site and building type are fundamental cores of its design development and construction process. Projects from two different locations or have two different function can be very dissimilar that it will possibly require two different solution. By creating framework for "Thai contemporary timber construction system" its development can be more focused, efficient and result in better quality. Therefore, location and building types for this proposed system will be determined in the following sections.

Choosing region

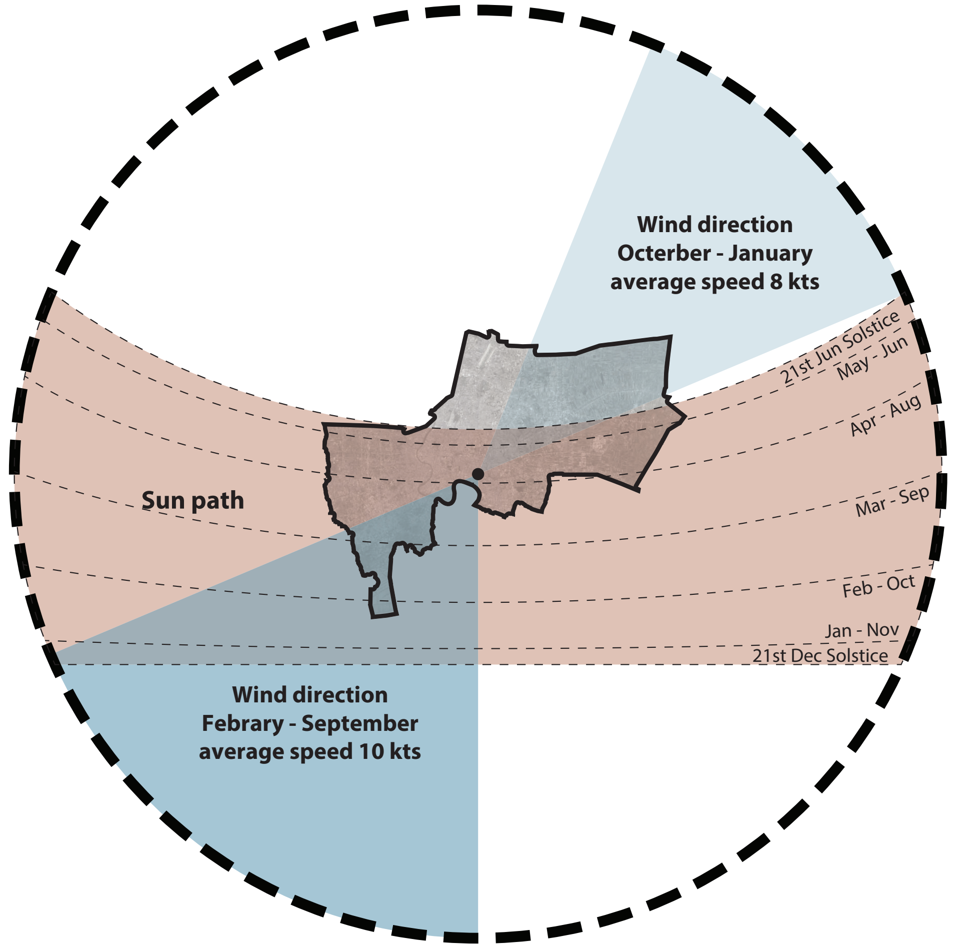
Climate is one of the most important aspects in every building design. The information of geographical contexts needs to be understood before "Thai contemporary timber construction system" can be developed. Thailand is a country in Southeast Asia and in Köppen Classification, most of the its land situated in the climate of Tropical Savanna. This climate has high amount of rainfall with pronounced dry seasons[3]. Climate in Thailand remain rather constant throughout the year with minimal temperature fluctuation. Difference of climate in each region is also rather mild. Some regions are dryer than the others and some has slightly higher temperature[4]. However, this small difference in climate is still relevant in the topic of architecture. This is evident in vernacular architecture, where each region has its version of design which is more suitable for their climate. Choosing the suitable region in Thailand as a framework will considerably affect the development of "Thai contemporary timber construction system".



Bangkok temperature
All year average = 28.9°C
Highest month average (April) = 30.6°C
Lowest month average (December) = 26.1°C

Bangkok precipitation
Total year average amount = 1450.3 mm
Highest month average amount (September) = 30.6°C
Lowest month average amount (January) = 26.1°C

3. Weatherbase. (2019). Bangkok, Thailand Köppen Climate Classification (Weatherbase). [online] Available at: https://www.weatherbase.com/weather/weather-summary.php3?s=55484&cityname=Bangkok,+Thailand [Accessed 27 Aug. 2019].
4. Thai Meteorological Department. (2018). Available at: https://www.tmd.go.th/info/info.php?FileID=56 [Accessed 21 Oct. 2018].
5. Stat.dopa.go.th. (2018). [online] Available at: http://stat.dopa.go.th/stat/statnew/upstat_age_disp.php [Accessed 21 Oct. 2018].



As previously mentioned, maximizing the positive impact is important to this thesis. Therefore, choosing the location for the project which has higher exposure to the population is more preferable. In Thailand, population density is concentrated in the central region, especially around the capital Bangkok and its municipality. At the end of 2017, population of Bangkok is reported to be 5,682,415 people. The city is home to over 13% of the country's total population, and more than 10.6 million registered people were reported to live in the Bangkok Metropolitan[5 6].

In Bangkok, the temperature ranges from 25-35°C throughout the day. The temperature remains constant year-round, except a few days or weeks of cooler period in November or December. Humidity in Bangkok is average around 70% in winter and summer, while reaching 80% in the rainy season. The sun has significant effects on humidity. Under its effect, humidity dropped to 40% and can goes up to 80%, or in extreme cases 95%, when it is raining or during the night[7.] Special consideration for humidity is particularly important in this project, since the main construction material will be wood based and it is a hydroscopic material. Sun radiation and wind are another two elements that influence architecture. Situated near equator, day time remain constant throughout the year in Thailand. The sun angle is high in this region. This make overhang elements very effective for sun protection. Solar radiation is the most important factor for indoor comfort of the buildings in Thailand. During day time, proper protection is needed, in order to prevent the interior of the house from heating up to a non-livable condition. As for the wind, the only factor that can affect buildings is its direction. In November to February wind came from the northeast, while in the rest came from southwest[8 9].

6. Worldpopulationreview.com. (2018). [online] Available at: http://worldpopulationreview.com/world-cities/bangkok-population/ [Accessed 21 Oct. 2018].
7. CHIRARATANANON, S. and HIEN, V.D. (2011). Thermal performance and cost effectiveness of massive walls under Thai climate. Energy & Buildings, 43(7), pp. 1655-1662.
8. Windfinder.com. (2019). Windfinder.com - Wind and weather statistic Bangkok Pilot. [online] Available at: https://www.windfinder.com/windstatistics/bangkok_pilot [Accessed 27 Aug. 2019].
9. Sunearthtools.com. (2019). Calculation of sun's position in the sky for each location on the earth at any time of day [en]. [online] Available at: https://www.sunearthtools.com/dp/tools/pos_sun.php?lang=en [Accessed 27 Aug. 2019].

Building type

Building type is another important factor for the development of "Thai contemporary timber construction system". Since maximizing the impact of this project is one of its core motivations, the decision for building type need to correspond with this principle. Residential buildings are the most common building type. According to a statistic by "National Statistical Office of Thailand" in the year 2010, the most common forms of residential buildings in Thailand are "Single-detach house", "Row house" and "Apartment" in this respective order. Single-detach house dominate the other two residential building types by a large margin at 72.3%. Row-house has 17.5% and Apartment has 9.3%. Even though this is not a recent data, it can still depict the current situation of Thailand, since the difference between the numbers of each building types are very high[10].

Another form of construction that also dominates Thai construction industry is commercial housing. There are several reasons that lead to this prolific nature of Thai commercial housings. In Thailand, architect as a profession has a certain degree of obscurity to general population. Sophisticated design that architects can offer are not the main criteria for common Thai people. They mostly based their decision on price and location of the house. The fee for architects is an extra cost that most of the Thais are not willing to pay. Even though design quality can still be appealing to them, it must come with a minimum cost. Project houses fit all of these criteria extremely well, since they can provide a moderate design and building quality with economical price. Another more relevant factor which contributes to the success of commercial housing is its ability to build actual house prototypes. Show-units are built for almost every housing project before the actual construction is finished. This practice also includes rooms for apartment projects and will be demolished when the sale process is done. This real-life prototype allows the Thai to see their future dwellings before they make the purchase and give commercial housing an extreme advantage over architect designed houses.

There are many attributes of commercial houses that are compatible with "Thai contemporary timber construction system". Repetitiveness nature of commercial house design is one such attribute and should be fully capitalized in this system. This repetitiveness allowed one or few designs to achieve a large number of buildings. In the situation when timber construction is not a normal practice, replicating large-number of buildings with one design is a good learning platform for timber construction practitioners. Designers can take time to develop design skills and knowledge, while the builders can carefully develop their construction technique with less challenge and more financial incentive. Additionally, commercial house can respond to more demand with fewer building designs. This is particularly helpful in the early stages of development for contemporary Thai timber construction industry, when the number of practitioners in this construction type is still low.

fig 5. Show-unit

fig 6. Sale Gallery

fig 4. Bangkok Street - photo : Viriyaroj B.
fig 5. Show-unit - photo : Viriyaroj B.
10. Statbbi.nso.go.th. (2018). [online] Available at: http://statbbi.nso.go.th/staticreport/page/sector/th/01.aspx [Accessed 21 Oct. 2018].

fig 7. Commercial House

fig 8. Commercial Row House

fig 7. Commercial House - source : https://www.tnews.co.th/social/496972/
fig 8. Commercial Row House - photo : Viriyaroj B.


fig 9. Bangkok Street

III. Design Principles

Establishing design principle is the next process for the development of "Thai contemporary timber construction system". Design principle is needed in order to create a system that is suitable with the developed framework and responding to the overarching goal of this thesis.

In order to establish suitable design principles for "Thai contemporary timber construction system" a better insight of current Thai construction industry toward timber construction is needed. This insight can be improved through the perspectives of different stakeholders in Thai construction industry. Therefore, series of interviews have been conducted on these stakeholders, and will be used as basis for the development of design principles. The interviews were executed through a semi-structured interview with several determined questions and were aim to explore their thoughts on timber as construction materials. The questions in these interviews are as following.

1. What is the most commonly used construction material by the interviewee?

2. What influence this material decision?

3. Has the interviewee considered using timber as construction material in his/her work?

If the answer of the 3. question is "Yes"

4. What is the reason for considering timber as construction material?

In the case that the answer for 1. question is not timber

5. Why timber was not chosen in his/her work?

If the answer of the 3. question is "No"

6. What is the reason for not considering timber as construction material?

In the case that the answer for 1. question is not timber

7. What would make the interviewee consider timber in his/her work?

The interviews were conducted on people with various roles in Thai construction industry. The list interviewees are 3 architects, 6 structural engineers, 2 real estate developers, 1 construction contractor and 8 builders. The result of these interviews will be presented in a summarized form in the following section. Many of the interviews were conducted in groups and will be presented as such.

Interviewee – a principle architect (small architectural firm)

1. Concrete or steel construction
2. They are the more widespread from of constructions. Designers and builders are more comfortable to work in these types of construction.
3. Yes
4. Wood has excellence aesthetic quality. Due to its high cost, it is more preferable to be used in the elements that contribute to the appearance of the building.
5. Price and rarity of wood is the main obstacles for timber construction. Finding these timbers along with the knowledge attached to it adds a lot of additional work to the designers. The skill that builders required to work with wood is another important factor.

Interviewee – 2 freelance architects

1. Concrete or steel construction
2. The builders are more familiar with these construction types. Steel may have advantage in the future due to its availability and fast construction time.
3. Yes
4. Wooden construction has great aesthetic. In some province, in the countryside of Thailand, carpentry for timber construction is well-established, especially in the case of traditional architecture.
5. The cost for construction grade timber has to be lowered for it to become competitive with concrete and steel. The knowledge of climate adaptation and insect attack prevention also have to be more developed.

Interviewee – 3 senior structural engineers

1. Concrete or steel construction
2. Construction cost is the main factor for this decision. Steel has started to be more common, especially for prefabricated construction.
3. Yes
4. It is the material for the future because of its renewability. Timber as construction material has potential for Thai market. This can be seen from the widespread timber substituted products in Thailand.
5. Price of timber is too high and the construction knowledge is not well-developed in Thailand. Wooden buildings are mostly associated with traditional architecture for the Thais. Termites is also another leading concern for Thai users.

Interviewee – 2 principle structural engineers

1. Concrete
2. Concrete required less maintenance and is superior in the subject of fire-resistance. There is an emerging trend of using steel in structural material, especially in long-span structure and prefabricated construction.
3. Yes
4. Wood has superior aesthetic and it is easy to work with if it is accompanied by proper construction knowledge.
5. Longevity, flammability and termites are main obstacles for timber construction. Durable wood is also very costly.

Interviewee – a senior structural engineers

1. Concrete and in some cases steel
2. Concrete is the most preferable choice because of its low cost. It also leaves a lot of room for error and require less preparations.
3. No, especially in structural members, but wood might be considered for finishing elements.
4. Wood is costly and require more maintenance. Each wooden element has slightly different in its appearance, making it harder to replace. Skilled carpenters are difficult to find, resulting in the need for more maintenance.
5. Timber construction has better indoor temperature and indoor climate quality, but it has to be more competitive in term of price to be considered.

Interviewee – a real estate developer (small scale company)

1. Concrete
2. Concrete is very durable and it is currently the cheapest option. Thai builders are more familiar with concrete construction.
3. No
4. Price of timber and its durability is the reason for not considering wood as the main material in buildings. Consistence wood quality is very crucial for the sale of commercial housing. Wood finishing is also prone to defect making it less appealing for the buyers.
5. Timber might be considered if good quality wood is available. It can be use in high-end commercial houses.

Interviewee – a real estate developer (public company)

1. Concrete
2. It is the most common construction material with low price. There are more skilled builders in concrete construction than other construction types.
3. No
4. Timber construction require skilled builders, construction knowledge and proper site management. Wooden finishing is more susceptible for defect, making it more difficult to sell the houses. It is also not compatible with the use of air-conditioner.
5. A lot of promotion and user's exposure are required for the development of timber construction. Environmental awareness can be an important factor for choosing timber construction in the future.

Interviewee – a construction contractor (small scale)

1. Concrete, steel can be chosen in some cases
2. Concrete construction is the type of construction that his builders are the most familiar with. It is cheap, common and has a reliable outcome.
3. Rarely
4. Timber is expensive and durable wood is hard to procure. His builders are not proficient with timber construction. The standard for construction is also not developed, making it more difficult to practice.
5. Wood has good aesthetic quality. It also gives the owner a sense of luxury and uniqueness. Fast construction time can be a valuable aspect for timber construction, but the price of timber has to be lower with higher quality product.

Interviewee – a builder

1. Concrete
2. It has low cost and high durability.
3. No
4. Rarity, expensive and low durability are the reason for not choosing wood.
5. –

Interviewee – a builder

1. Concrete
2. It is cheap and durable. Builder skills are tied to concrete construction.
3. No
4. The threat from termites and the durability of wood are the reasons.
5. With termite prevention method and better construction knowledge, wood might have more opportunity because of its superior aesthetic quality.

Interviewee – a builder

1. Concrete
2. The builder skills are more developed in concrete construction,
3. No
4. The lack of skilled carpenters and good quality wood are the main reasons.
5. People in general like wood aesthetic, removing the threat of termite might make people more comfortable to choose wood.

Interviewee – a builder

1. Concrete
2. Durable material
3. No
4. Wood is not durable.
5. -

Interviewee – a builder

1. Concrete
2. Concrete construction is the most common construction type.
3. No
4. The price for wood is high and the craft of timber construction is disappearing.
5. -

Interviewee – a builder

1. Concrete
2. The skill of builders is more developed in concrete construction practice, making it easier and faster to build.
3. No
4. Wood has low durability and it is difficult to procure.
5. Timber construction need lower material cost and more skilled builders.

Interviewee – a builder

1. Concrete
2. It is more durable.
3. No
4. Wood has low durability.
5. –

Interviewee – a builder (focus on renovation projects)

1. Steel and wood
2. The material choice is based on the client. This builder has developed skill in timber and steel construction.
3. Yes
4. Wood is light, making it the most preferred construction material for him. However, it suffers from the threat of termite and should be use carefully.

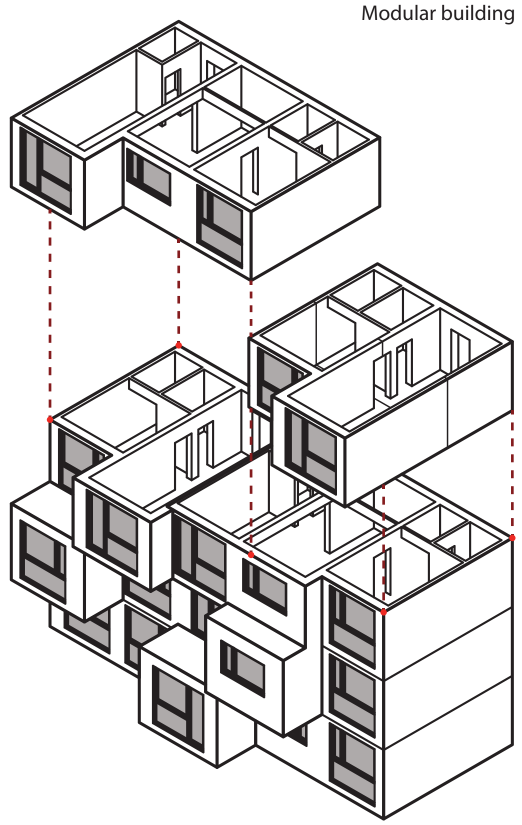
The result of the interviews are mostly coherent, especially when they came from the same professional perspective. The problem of material cost, material rarity and skilled builders are the recurring answer in most of the interviews. Threats of "Formosan subterranean termite" is another concern that has been often mentioned[11]. Aesthetic of wood is mostly the main reason for the interviewees to choose wood as construction material. Each profession has specific concern based on their role in construction. Architects and engineers are the group of interviewees that have considered using timber in their design. Designers has particular concern with builders' skills, while real estate developers are concern with the quality of material. For the interviewed builders, durability of wood seems to be their main concern. This might due to the lack of confidence in their timber construction skill that has translated to this concern. Steel has also been mentioned as the material that are often used and considered by the interviewees, especially among the builder designers.

These interviews, has given some insight of the current timber construction situation in Thailand. This insight will be further applied to the development of "Thai contemporary timber construction system" in the following sections and chapters.

11. En.wikipedia.org. (2019). Formosan subterranean termite. [online] Available at: https://en.wikipedia.org/wiki/Formosan_subterranean_termite [Accessed 27 Aug. 2019].

fig 10. Wood Products

Modular building



Standardization and modularity

Complementing the strength of commercial housing is essential to the design principles of "Thai contemporary timber construction system". Standardization and Modularity are the concepts that have high compatibility with commercial housings. Even though, one house design can be replicate to a limitless amount of buildings, it is not practical to force every house only to fit in one design. Eventually, a new design has to be made, in order to respond to difference challenges from site limitation, geographical requirements or user's preferences. The process of developing new design will compromise the efficiency of replication in commercial housing. Therefore, each new design needs to adhere to concepts or set of rules that would prevent them from losing this strength of repetitiveness. Adopting both standardization and modularity is the design principle which is chosen to maintain this strength.

Standardization will be applied to components and details of building designs. This concept has been used in the development of contemporary timber construction and have successfully enable it to gain worldwide recognition. It has also developed timber construction in to an economic, reliable and fast construction solution for modern requirements. This can help streamlining the design process of building designers and assembling process of builders for "Thai contemporary timber construction system"[12 13 14].

In essence, modularity adds variety to project houses, while maintaining its efficiency. This is achieved by allowing part of previous work to be replicated in future projects. Modular design can prevent building designers from starting every project from zero, thus makes new designs more feasible to them[12].

The efficiency of the system can be further enhanced by coordinating the modular units with the standardized elements. This will create an optimized solution, where each modular unit can be created with high material efficiency, and can be attain by building these modular units based on the dimension of standardized elements. The positive aspects of this optimization will be escalate with every replication of modular units.

fig 10. Wood Products - photo : Viriyaroj B.

12. COFFMAN, B.E. (2004). THE POWER OF RISK: POETICS OF STANDARDIZED WOOD CONSTRUCTION, University of Cincinnati.

13. LENNARTZ, WILHELM, M., and JACOB-FREITAG, S. (2015). New Architecture in Wood : Forms and Structures

14. KOPPELHUBER, J., BAUER, B., WALL, J. and HECK, D. (2017). Industrialized Timber Building Systems for an Increased Market Share – a Holistic

Efficiency and flexibility

Even though, concentrating on replicable commercial houses is a logical decision for "Thai contemporary timber construction system", there is still a pitfall from committing only to this architectural type. As a result of its efficiency, commercial housing design greatly limits the participation of building designers. Since shifting Thai construction industry toward bio-based material is the goal of this thesis, a decision that disregards an important group of stakeholders from taking part in this development is not ideal. Efficiency and replicable design need to be the focal point of "Thai contemporary timber construction system" in order to achieve its goal. However, it should also provide the flexibility for designers to engage, experiment and apply this proposed system in their professional works. Therefore, development of system with a balance between efficiency and flexibility will be one of the most important aspect in this thesis.

"Thai contemporary timber construction system" should be developed in a way that both commercial houses and custom houses has opportunities to utilized it to a satisfactory degree. In the case of conflicting design decision between commercial house and custom house, the former should still have higher priority than the latter, since it is more compatible with the goal of this thesis. Nonetheless, this system should not fail to demonstrate its application in custom design scenario.

Prefabrication

Another design principle that can further support "Thai contemporary timber construction system", especially in construction process, is prefabrication. Prefabrication is highly compatible with timber construction. This came from both its strength and weakness. Wood is a light weight material, which allowed ease of transport from workshop to site, for large pre-assembled building units, making the process cheaper and safer. Its weakness to climate vulnerability can also be minimized with prefabricated construction. Assembling process in the workshop is far easier to be climate protected than on site construction. Rain in particular, is extremely harmful for wood in buildings, especially to the component that are not intended to be exposed to the environment such as load-bearing or interior elements. This factor is extremely important in Thailand because the precipitation in tropical climates is very high. Prefabrication helps reduce the risk of climate exposure to construction process and it is very advantageous to be included in "Thai contemporary timber construction system".

Builders can also benefit from prefabricated construction. Pre-assembling components in the workshop allowed builders to be familiarized with timber construction in a more control and secure environment[14]. Furthermore, it is less challenging and more feasible to employ a few experienced builders for more intricate assembly of timber construction components in a workshop. These components can be transport to each construction site later on and can then be assembled on site with less skilled local builders. This method has more efficient usage of construction workers than on-site construction and will be highly advantageous to the early process of establishing timber construction in Thailand.

fig 11. Prefabricated Construction

fig 11. Prefabricated Construction - source : https://www.homag.com/en/news-events/case-studies/detail/high-degree-of-prefabrication-allows-for-top

14. KOPPELHUBER, J., BAUER, B., WALL, J. and HECK, D. (2017). Industrialized Timber Building Systems for an Increased Market Share – a Holistic Approach Targeting Construction Management and Building Economics.

fig 12. Thai Vernacular Architecture

fig 13. Thai Contemporary Architecture

fig 14. Prefabricated Timber Architecture

fig 12. Thai Vernacular Architecture photo : Viriyaroj B.
fig 13. Thai Contemporary Architecture photo : Viriyaroj B.
fig 14. Prefabricated Timber Architecture - photo : Viriyaroj B.

Timber construction knowledge

The sources for timber construction knowledge need to be established before the development of "Thai contemporary timber construction system". There is currently no compiled knowledge of contemporary timber construction in Thailand. Therefore, these knowledges have to be gathered from other relevant sources. The knowledge of climate adaptability for timber construction is needed to design a proper functional timber building in Thailand. In this subject, vernacular architecture has a lot of applicable knowledge that can be studied from. Wood is the main material of this type of architecture and climate adaptability is the aspect that Thai vernacular architecture is extremely excels at. This make it an exceptional source of knowledge for climate adaptation in timber buildings in Thai context. Availability of information is another important aspect. Vernacular architecture in Thailand is well documented and can be easily studied compare to other contemporary timber houses.

The actual "Ruen Thai" itself is not a rare sight in the central part of Thailand, the chosen location for "Thai contemporary timber construction system". Despite its common presence throughout the region, the craft itself is struggling to pass on its knowledge and most of the "Ruen Thai" are the old and preserved buildings. One of the reasons that Thai vernacular find its difficulties in the current time is how its functions and details are tie in to the traditional lifestyles. There are several spaces in vernacular Thai house that has become obsolete in present day. Elevated ground floor is one such example. Traditionally, the space under the houses is used for storing tools, agricultural products or animals. Nowadays, this is the functions that are not necessary to most regular Thais and almost every Thai house that has been found during the study of "Ruen Thai" has this space filled-in with rooms made out of concrete and bricks. Some of the required function in contemporary house is also missing in Thai vernacular architecture; e.g. toilet, bathroom or other indoor living spaces. Additionally, the enveloping elements of Thai vernacular architecture do not lend itself well to the use of air-conditioner, which is a mandatory device in the majority of modern Thai household. The house was not design to be airtight or insulated, since the climate in this region is bearable with just sun and rain protections. However, the standard of indoor air comfort has completely changed from the older times and this issue needs to be solved, responding to the new standard. These are some of the examples, which show that simply using Thai vernacular architecture as the only source of timber construction knowledge is not sufficient for "Thai contemporary timber construction system"[7 15].

The knowledge from Thai vernacular architecture should be accompanied with study of Thai contemporary houses. Contemporary functional spaces are the aspect that Thai vernacular architecture is lacking, and it has to be studied from contemporary buildings. All of the relevant knowledge will be solidified and used in conjunction with the knowledge gather from "Ruen Thai". The study of contemporary houses has another application for "Thai contemporary timber construction system", since commercial house is a building type it needs to build. Commercial houses are the concept that was not corresponds with the concept of Thai vernacular architecture, because it was built and used mostly by the users.

Another gap in knowledge that needs to be filled in is the knowledge of building envelopments in contemporary timber construction. As previously mentioned, airtightness is the aspect that was not important to Thai vernacular architecture, but needs to be achieved in "Thai contemporary timber construction system". The knowledge from foreign countries with developed contemporary timber constructions is the potential answer to this problem. A decision has to be made, whether which region is the suitable source of timber construction knowledge. Availability of resources is a strong criteria for this decision. The source of the knowledge that has the highest availability in this project came from European timber construction. Climate conditions in some European countries with developed timber construction are extreme, especially in terms of temperature difference between indoor space and outdoor space. By studying envelopment designs of timber construction from Europe, which can provide good weather protection in extreme condition, will be advantageous to "Thai contemporary timber construction system"[16 17 18]. Building envelopments will not be the only element that should be study from European timber construction. Primary and secondary structure, timber joints, wood surface protection or any other knowledge should all be considered and should be integrated to others knowledge. Industrialization in European timber construction industry can also be of use to this thesis. Glued wood products can address the problem of scarcity for construction grade wood in Thailand. The technique used to create this product enable larger member of timber to be created from smaller trees. This allowed shorter harvest cycle but still yield product with similar properties. Large-scale investment, which will be required for the inception of sustainable forestry in Thailand, is one of major the obstacles for the development of Thai timber industry. Shortening harvest cycle is extremely valuable, because it enables faster returns of investments. This technology of glued wood product has potential to help overcoming this obstacle.

7. CHIRARATANANON, S. and HIEN, V.D. (2011). Thermal performance and cost effectiveness of massive walls under Thai climate. Energy & Buildings, 43(7), pp. 1655-1662.
15. TANTASAVASDI, C., JAREEMIT, D., SUWANCHAISKUL, A. and NAKLADA, T. (2007). Evaluation and Design of Natural Ventilation for Houses in Thailand, Journal of Architectural/Planning Research and Studies Volume 5. Issue 1.

fig 15. Finnish Forest

Alternative timber sources

In order to alleviate the problem of material scarcity, alternative timber can also choose to be imported from countries with abundant wood supply. There are many countries that have enough supply of lumber and export it as an industry. Several leaders of global lumber exports are European nations. Since this project has already identified European timber construction as one of its main sources of knowledge, it is fitting that the alternative source of timber should also has the same origin. In contrast to local timber, wood from European coniferous tree has much more competitive price with other construction materials in Thailand. Timber from this region also has reliable certificate, guaranteeing that these lumbers came from a sustainable source, while timbers from Thailand are almost impossible to track its origin. This creates a risk of choosing illegally cut timber for building construction, thus creating negative impact to our environment rather than a positive one.

Nevertheless, it is expected that other negative impact from this solution can emerge; e.g. additional costs for shipping, CO_2 emission from longer transport or effect of tropical climate on European softwood. To determine whether this solution is preferable, SWOT analysis for timber construction in Thailand will be conduct with local wood as its main material. This process is done to discover negative aspect of local timber. The next process is analyzing the benefit of using European timber in Thailand, in order to determine its possibility of alleviating negative aspect of timber construction with local wood. Lastly, positive effect of using European softwood have to be compare with the negative effect it creates before the final decision is made.

SWOT analysis of timber construction

Strength

1. Low CO_2 emission

Timber has significantly lower CO_2 emission compare to concrete. One cubic meter of timber is estimated to emit around 160 kg of CO_2, while concrete can emit 300 kg of CO_2. These number can change depends on specific type of material or manufacturing process[19 20].

16. HUGHES, T., STEIGER, L. and WEBER, J. (2007). Timber Construction
17. KOLB, J. (2008). Systems in Timber Engineering
18. HERZOG, T., NATTERER, J., SCHWEITZER, R., et al. (2012). Timber Construction Manual.
fig 15. Finnish Forest - photo : Viriyaroj B.

2. Light weight

Wood is much lighter than concrete with the same mass. Concrete has the density around 2.200 kg/m3. The heaviest wood has the density of 1.260 kg/m3 and most of the wood species that are used for construction has no more than 1.000 kg/m3. This has benefit on both construction process and transport of materials making these processes easier to execute. Prefabricated construction is also more compatible with materials that has lower weight, since the weight of elements that needs to be transport are multiplied from pre-assembled elements[19 20].

3. Renewable material

As a renewable material, the source of timber will always be stable as long as there are investments in the industry. Non-renewable materials however, will eventually face the problem of resource depletion, which will eliminate their availability in the future.

4. Wood aesthetic

As previously mentioned, aesthetic of wood is well received by Thai people. This advantage can be emphasized on the design by putting wood surface on display. The elements that can utilized this positive aspect are finishing of the buildings.

5. Less wet trade

Many negative aspects during construction can be reduced with less wet trades on site, e.g. site pollution, neighborhood disturbance, use of machineries, etc. The process of wet trades in concrete construction also took significantly longer than assembling processes of timber construction. More and more real estate developer values fast construction time over small financial margins. In a large volume construction, less time translate to less labor, less management and less expenses. This is an attribute of timber construction that can be appealing to commercial house developers.

6. End of life opportunity

Unlike concrete, which currently can only be recycled as gravels or ended up in the landfill, wood-based products have plenty of possibilities after a building has been demolished. Reusing, Recycling or Cascading wood can be done to utilize this material to its full capability. More importantly, second-hand wood is an already established market in Thailand. This is partly due to the scarcity of this material. Often time second-hand wood is chosen over virgin woods because the quality of local timber production is not transparent and reliable. Using second-hand wood has less risk of supporting timber from illegally cut sources. Virgin woods are sometime not properly dried and can be damaged or deformed during their early usage, making them undesirable. Good condition second-hand wood is therefore preferred, since they have been processed long ago and are less likely to suffer more damage during their new application. To sum it up, the fact that wood retain its financial values during its usage is well-known in Thailand. This quality can be used to persuade Thai people to choose timber construction over conventional concrete construction materials.

Opportunity

1. Protected tree species regulation

In 2019, a regulation regarding extreme protection of several rare and valuable tree species has been lifted. This regulation forbids the felling of these listed species of tree in any circumstance. This include the tree which grew in privately own properties. The effect of this regulation discourages these trees from being intentionally planted. With this regulation being lifted, many Thai landowners have shown interest in growing these protected trees species for commercial purpose. This can open a door for future development of sustainable forestry and create more source of timber for Thai buildings, thus eventually reducing its price.

19. Antti Ruuska. (2013) Carbon footprint for building products ECO2 data for materials and products with the focus on wooden building products. VTT Technology 115. 126 p. + app. 2 p.
20. Prof. Geo7 Hammond & Craig Jones. (2011) Inventory of Carbon & Energy (ICE) Version 2.0

2. Environmental concern.

In recent years, environmental awareness has increasingly gained the attention of Thai people. Many cities in Thailand, including its capital Bangkok, have been polluted with heavy smog for two consecutive years and the third one is to be expected. This smog last for several month and will cause long term damage to the health of Thai people[21]. The concern for air pollution is currently high among the Thais. Conventional concrete construction produces dust on construction site, but this is not an issue in timber construction. Even though dust from concrete construction does not contribute to the creation of smog, the awareness for clean air environment has already been established by this event. The promotion of timber construction can benefit from this concern, since they will be more appealing to environmentally concerned populations.

fig 16. Bangkok Smog

fig 17. Steel Construction

fig 16. Bangkok Smog - source : https://www.bangkokpost.com/thailand/general/1693020/seeing-through-asias-smog-smokescreen
fig 17. Steel Construction - source: Viriyaroj B.
21. the Guardian. (2019). Toxic smog forces Bangkok to close hundreds of schools. [online] Available at: https://www.theguardian.com/world/2019/jan/30/toxic-smog-forces-bangkok-to-close-hundreds-of-schools [Accessed 27 Aug. 2019].

fig 18. Thai Wood Store

3. Development of steel construction

Steel as structural material is widely seen in Thailand, especially when used in conjunction with concrete construction. The process of assembling steel construction shared many similar principles with timber construction. Because of this reason, builders with steel construction skill might have fewer obstacles being familiarized with timber construction. This project can also be developed in a way that can take advantage of this situation. It is already common to see the use of steel element to enhance timber construction in contemporary timber buildings. Designing the detail of "Thai contemporary timber construction system" whicht focus on the integration between steel and timber might alleviate the lack of timber construction builders early on. One of an important challenge to this principle is keeping the amount of steel usage to a minimum, since steel has significance higher CO_2 emission rate than wood. Utilizing too many steel elements in this project will undermine its positive environmental impact.

Weakness

1. Difficulties in wood procurement

Local woods are difficult to procure. The price for this material is high. They are also not commonly found on the shelf of general construction material stores. They are, instead, usually sold by dedicated wood stores. Finding a specific store that has required timber products is an additional challenge to the designers, builders and owners.

2. Lack of timber certification

There is no established certification or standard for local wood in Thailand. Woods are only differentiated by species and sizes. Origins of these timbers are almost impossible to determine. Strength and surface quality can only be discovered after the products have been delivered. These obstacles put additional amount of substantial workload to designers and builders[18].

3. Lack of skilled practitioners

There are not enough skilled practitioners of timber construction in Thailand. The incentive for practicing this craft is very low, since there are no demands for wooden buildings. Without demand for timber, there are less opportunity to develop the skills and knowledge of timber construction. This problem is escalated by the skill ceiling of timber construction, since it is a rather complex craft. It requires a lot more planning, precision, knowledge of the materials and site protection than concrete construction[12]. Lack of opportunities in turn makes it difficult to build good quality wooden architecture in Thailand. As a result, clients become reluctant to choose timber construction, reducing the audiences for this type of building.

fig 18. Thai Wood Store - photo : Viriyaroj B.

12. COFFMAN, B.E. (2004). THE POWER OF RISK: POETICS OF STANDARDIZED WOOD CONSTRUCTION, University of Cincinnati.

18. HERZOG, T., NATTERER, J., SCHWEITZER, R., et al. (2012). Timber Construction Manual.

Threats

1. Underdeveloped regulation for timber construction

Timber construction is severely marginalized in Thai regulation. There are only three times that the subject related to timber construction has been mentioned in regulation for building construction.

"Fire-resistant materials" means construction materials which cannot be burnt.
"Flammable materials" means construction materials which can be burnt.
Buildings which are not built mostly with Fire-resistant material cannot have more than 2 stories.

This regulation is extremely limiting to timber construction. The only workaround is using chemical to limit flammability of wood. However, this will have direct impact on costs of construction, limits wood's end of life opportunity and potentially polluting the environment.

2. Development of steel construction

The trend of building construction in Thailand has started to favor construction speed over small financial margin. Recently, the development of steel construction for houses has started to gain market share from construction industry. The largest construction company in Thailand has put a lot of investment in pre-design house using steel construction. Despite the benefit that this project can gain from development of steel construction, it can also become a threat. Steel houses have a lot of overlap positive aspect with timber construction. They are often promoted using fast construction time, reusability, less wet trade and less air pollution as their appeal to the market. The difference is that, steel construction is a more common practice and is trusted more by the Thais. More steel buildings in the market might result in lowered amount of concrete usage. However, timber is still superior in terms of positive environmental impact, and choosing steel over timber will diminish this impact in the long run.

Integrating European softwood products

The next step in this process is to compare the positive aspect of utilizing European softwoods to the negative impact it creates. This positive aspect will be determined by looking at "Weakness" and "Threat" of timber construction using local woods and using European timber to address those problems. Negative aspect of European softwoods will then be analyzed. Lastly, solutions for these negative aspects will be proposed and the decision for the application of European softwood will finally be considered, based on these factors.

fig 19. Softwood Products

fig 19. Softwood Products - photo : Viriyaroj B.

Weakness of local timber

1. Difficulties in wood procurement

The supply for European softwoods is abundant and can positively address this problem. The import softwood products are already existing in Thailand. These products came from various place including European nations like Finland. Price is the most important aspect in this situation. Unlike local wood, European softwood can be competitive with conventional materials in Thailand, if all of timber positive aspects are taken in to consideration. Glued wood products can also further reduce the price and making it more appealing for potential its customers.

2. Lack of timber certification

European softwoods have strong certification system; the sources of timbers can be tracked, ensuring sustainable source of wood is used. This certification system also contains relevant material information for designers and builders. Having a certification and standard system in Thailand can alleviate Thai timber construction in to a different level and should be done along with other construction developments. Introducing wood material along with its certification can be a gateway towards developing this standard in Thailand[18].

3. Lack of skilled practitioners

Species of timber affect the attributes of wood products; using wood without the proper knowledge of these attribute will reduce the quality of the constructed buildings. Fortunately, the knowledge of European softwoods is well researched and documented. Since, the lack of timber construction knowledge is one of the most important problem in this project, using this established knowledge of European softwood is logical. Additionally, current timber construction in Europe has been integrated with many industrialized processes. Industrialization of timber construction directly affects the manufacturing process of materials. Aside from production phase, there are many industrialization methods, tools and components that affect assembling process of the buildings as well. This industrialization can make the process of developing the skill of Thai builders easier and should also be considered[12]. This adopted knowledge still has to pay attention to the base skill of Thai builders and other relevant Thai contexts.

Threats to local timber

Importing European softwoods has minimum effect on the topic of threats. Both "Underdeveloped regulation for timber construction" and "Development of steel construction" can only be mitigated by successful and timely development of Thai timber construction.

Emerged weakness

1. Additional transportation process

It is to be expected that the negative impact from additional transportation will emerged by importing timbers as a solution. Increased transportation process means increased cost, increased energy consumption and increased CO_2 emission. Therefore, the amount of these impacts needs to be uncovered in order to assess this solution. The estimated cost for transporting timbers from Finland to Thailand is around 40 € per cubic meter per round-trip. This is equal to an increase of 13% of timber price in Finland. In this scenario the price of importing Finnish timber will be roughly 60% of the price of local Thai timber, which is substantially less[22].

In the case of CO_2 emission, emission from deep-sea container shipping is 8 gram of CO2 per ton per kilometer. The amount of CO_2 emission from shipping between Finland and Thailand will be around 0.4 kg per 1 kg of timber. This is a marginal increase in CO_2 emission for softwood, which is around 550 kg[23].

From these calculations, it can be concluded that, importing wood from Europe has marginal impact on both price and CO_2 emission. Nonetheless, this negative impact can be minimized further by increasing the efficiency of shipping process. This means that, importing pre-cut elements are much more preferable than importing pre-assemble elements due to its space efficiency. In addition, importing pre-assembled elements will create another negative impact by removing essential processes in construction, limiting the chance to learn and employment opportunities for Thai builders.

12. COFFMAN, B.E. (2004). THE POWER OF RISK: POETICS OF STANDARDIZED WOOD CONSTRUCTION, University of Cincinnati.
18. HERZOG, T., NATTERER, J., SCHWEITZER, R., et al. (2012). Timber Construction Manual.

Emerged threats

1. European softwood behavior in tropical climate

European softwoods have been thoroughly researched, for its application as building materials. Since they are the native material of European region, the context of its researched are focused on its application in European climate. This poses a problem of using it in a foreign context when the research has not been done as thoroughly. High moisture content in the environment exposes wood to the threat of bio deterioration. In the case of mould, environment with relative humidity more than 75% and temperature higher than 30 °C enable mould attack in wood. For decay, it is 90% of relative humidity in 30 °C temperature[24]. In Thailand, relative humidity fluctuates between 40-80% or 40-95% in rainy season. The high relative humidity periods are during rain or night time. With the chance for wood to dry during the effect of the sun, European softwood will be able to handle bio deterioration with proper designs. Species of wood also has effect on this issue. Between two European softwood species, pine (Pinus Sylvestris) and spruce (Picea abies), Pinus Sylvestris perform better against bio deterioration in high temperature and relative humidity. These are the general condition of tropical climate, which make pine wood a better choice for the imported timber in Thailand[25].

There is however, another serious threat for European softwood in the context of Thailand. Formosan subterranean termite is the species of wood eating termite that is endemic to many tropical or sub-tropical regions in the world including Thailand. These termites can cause destructive damage on any timber material and has caused problem to many local wood components or furniture in Thai buildings. Formosan subterranean termite does attack European softwoods or other similar species, and chemical preservatives are highly suggested to prevent termite attacks[26]. Using chemical preservative however, should be avoided, since it has effect on wood's end of life application and environmental pollution. Nonetheless, there is a method to handle this problem without the preemptive use of chemical in every wooden element. Unlike bio deterioration, termite attacks can be visually observable. Formosan subterranean termite in particular, attacks buildings from underground. This means that, building designs that allowed visual inspection, especially under the house, are desirable for "Thai contemporary timber construction system"[27]. When termite attacks occur, insecticide can be used to stop this threat. Pyrethroid Insecticides is the preferred option for insecticides because of its several qualities. It has low effect on mammal an avian but it is dangerous to aquatic life. Therefore, its application near water sources should be avoided. Additionally, it has low volatilization and can be easily absorbed by soil or clay, which limit its proliferation[28].

Assessment of European softwood in the context of Thailand

From the assessment that has been conducted, using European has a lot of potential in the context of Thailand. Importing European timber as a solution can has positive effect on all of the local wood weaknesses. Furthermore, the emerged negative effects of importing timber are either marginal or manageable. However, the strongest positive effect of using European timber is its sustainable sources. Wood from sustainable sources is an invaluable material for designing building that aim for low CO_2 emission. From these reasons, this project will proceed with European softwood, as the main source of timber in its design, and pine (Pinus Sylvestris) will be the chosen species.

22. Freightos. (2019). Ocean and Sea Freight Rates | Container Shipping Rates | Freightos. [online] Available at: https://www.freightos.com/freight-resources/ocean-freight-explained/ [Accessed 27 Aug. 2019].
23. Ecta.com. (2019). [online] Available at: https://www.ecta.com/resources/Documents/Best%20Practices%20Guidelines/guideline_for_measuring_and_managing_co2.pdf [Accessed 27 Aug. 2019].
24. Meyer-Veltrup, Linda & Brischke, Christian. (2015). Fungal decay at different moisture levels of selected European-grown wood species. International Biodeterioration & Biodegradation. 103. 23-29. 10.1016/j.ibiod.2015.04.009.
25. VIITANEN, H.A. (1997). Modelling the Time Factor in the Development of Brown Rot Decay in Pine and Spruce Sapwood - The Effect of Critical Humidity and Temperature Conditions. Holzforschung, 51(2), pp. 99-106
26. MA, X., JIANG, M., WU, Y. and WANG, P. (2013). Effect of Wood Surface Treatment on Fungal Decay and Termite Resistance. BioResources, 8(2),
27. GHALY, (2011). Termite Damage to Buildings: Nature of Attacks and Preventive Construction Methods. American Journal of Engineering and Applied Sciences, 4(2), pp. 187-200.
28. PALMQUIST, K., SALATAS, J. and FAIRBROTHER, A. (2012). Pyrethroid Insecticides: Use, Environmental Fate, and Ecotoxicology. InTech

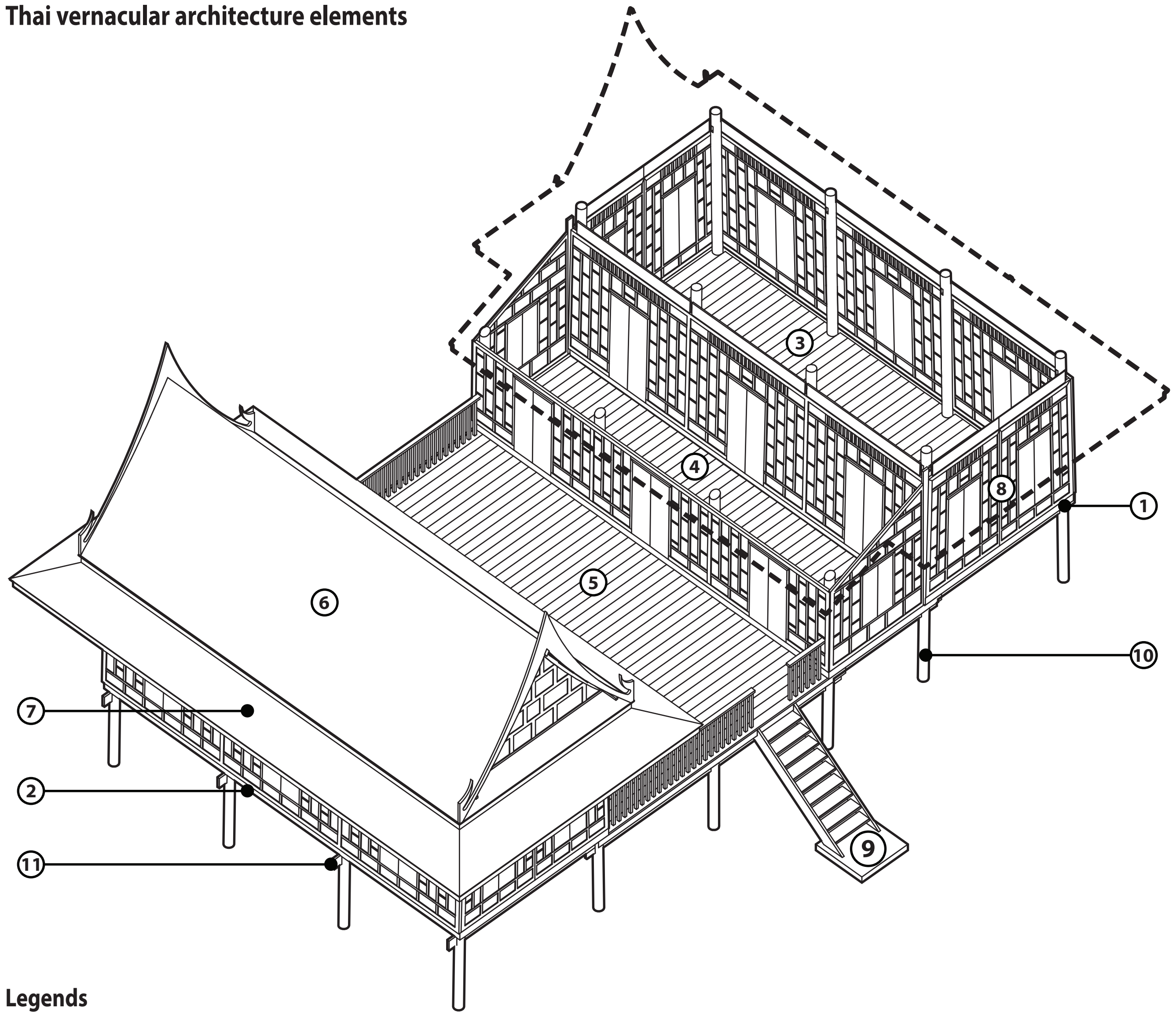
fig 20. Space under the House in Thai Vernacular Architecture - photo : Viriyaroj B.

IV. Timber Construction Knowledge

Thai vernacular architecture analysis

There are many variations of Thai vernacular architecture based on the region they were built in and the material they were constructed with. Thai vernacular architecture can be built with two materials, bamboo and timber. Timber is the material of choice in this project. Therefore, the timber-based vernacular architecture will be the chosen type. The principles design of timber based vernacular architectures are similar in all Thai regions. This is particularly true for their spatial functions. This type of architecture always has single storey with alleviated ground floor. In a building for extensive family, it consists of several room connected with a large central terrace. This terrace also serves as living area to the users of the house[29].

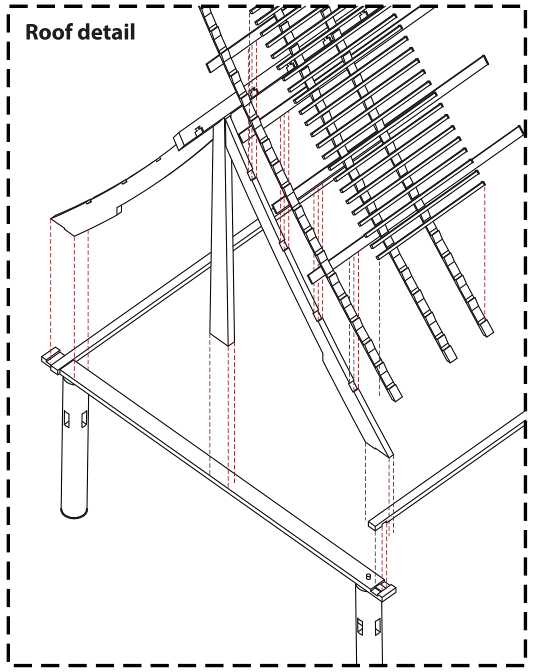
Thai vernacular architecture elements

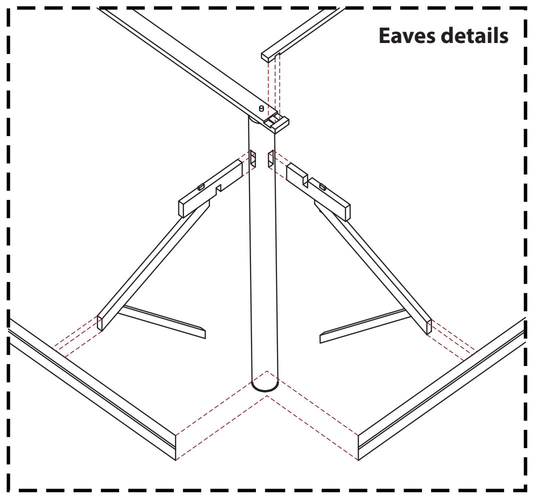


Legends

1. Timber construction
2. Single storey
3. Room unit
4. Veranda or porch
5. Central terrace
6. High-pitched gable roof
7. Extended eaves
8. Wood panel walls
9. Entrance
10. Elevated floor
11. Wood joinery

29. กรมศิลปากร. (2010). โครงการจัดทำองค์ความรู้ด้านการสำรวจสถาปัตยกรรมเพื่อการอนุรักษ์โบราณสถาน (อาคารเรือนทรงไทย)





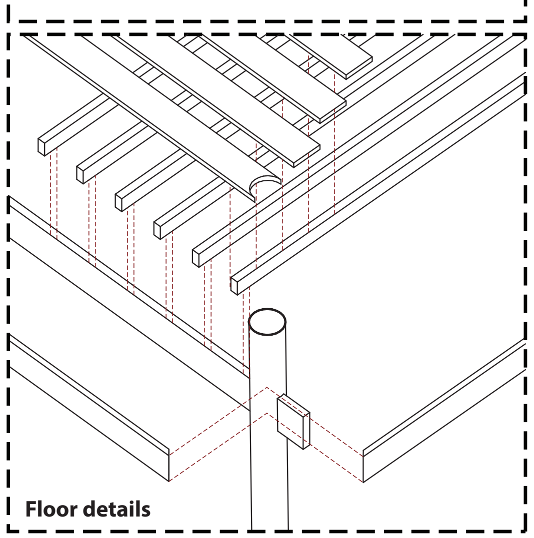


fig 21. Central Terrace

fig 22. Roof structure

fig 23. Veranda or porch

fig 21. Central Terrace
fig 22. Roof structure
fig 23. Veranda or porch - photo : Viriyaroj B.

Climate adaptation

Thai vernacular architecture is highly compatibility with traditional lifestyle and climate of Thailand. The climate adaptation is the aspect that this project will focus on in this analysis. This climate adaptation slightly differs between each region of Thailand. Even though, the climate different is mild, it is easily noticeable with basic knowledge in Thai vernacular architecture. Central region is the variation of "Ruen Thai" that is chosen to be studied in this project, since it is the region that is the focal point of "Thai contemporary timber construction system". In this region, the architectures are heavily influenced by three important factors from Thai climate, strong sun, monsoon rain and occasional flooding[30 31].

1. Flood adaptation design

Flooding is one of the few natural disasters that generally occurred in Thailand. In the past, water management through technology was not available, and the buildings have to survive through these floods. Elevated floor is the method used to handle this problem. The lifted space protects the indoor spaces when flooding occurs. This design also provides security to the users, since it limits the access of wild animal to the house. Lastly, space under the first floor is not wasted; it is used for storages, agricultural tasks or keeping livestock.

2. High pitched roof

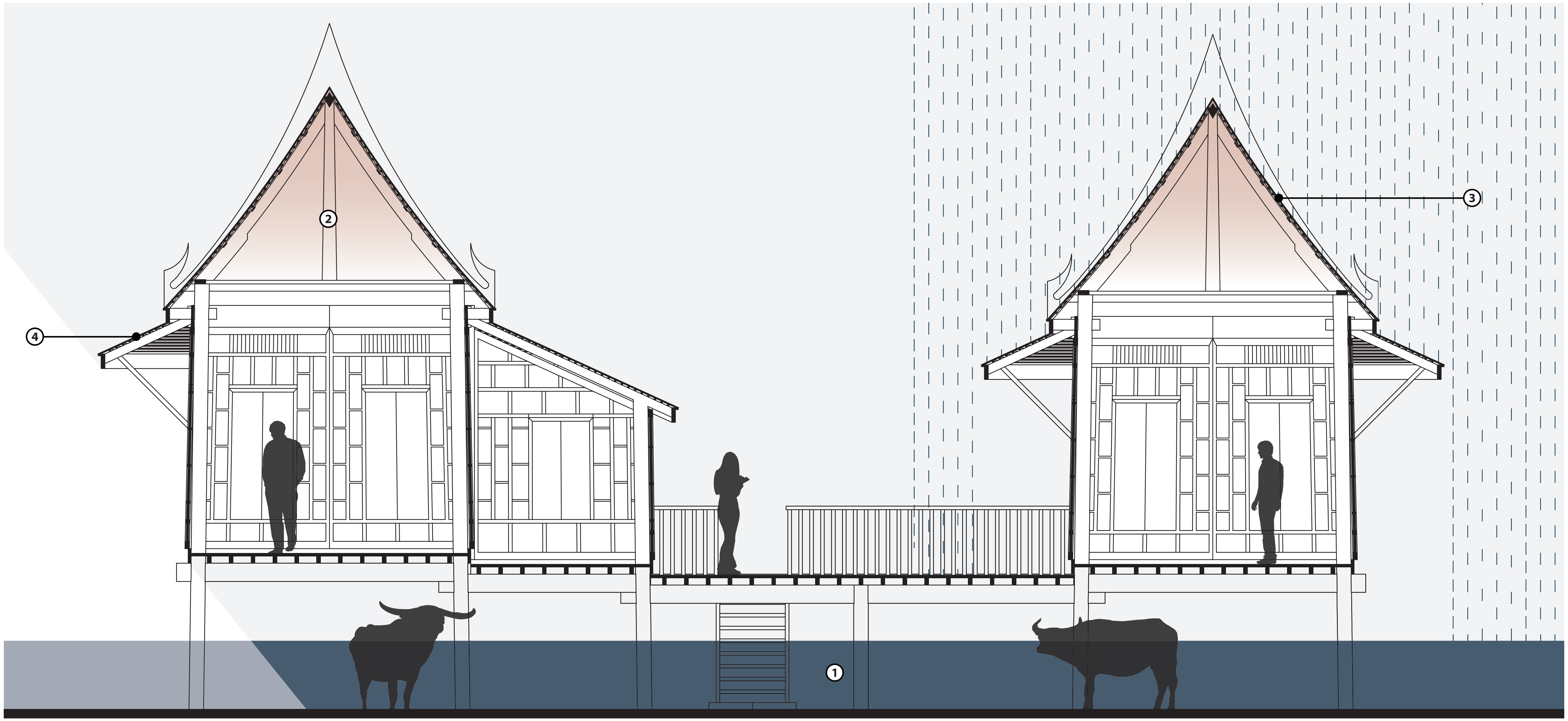
Heat from the sun is the most prominent factor for maintaining comfortable indoor temperature. Thai vernacular architecture uses high pitch roof to prevent indoor space from heating up. Space under roof created from a high-pitched roof performs as insulation, without the use of additional materials.

3. Steep roof angle

Rain in tropical climate can be very extreme. This creates a challenge of water leakage during heavy rain. Steep roof angle allows the rain to flow faster, which means the chance for water leakage is minimized. This design enables the use of thatch roof and other less water repellant materials in Thai vernacular architecture.

4. Horizontal shadings and eaves

Extended horizontal shading and eaves protect the house from strong sun in tropical climate. Since the sun angle is high in Thailand, horizontal shading and extended eaves are very effective for maintaining comfortable indoor temperature during day time.



30. RAMASOOT, S. (2013). Sustainability via Adaptability: Learning from the Traditional Thai House's Built-for-Change Architecture.

31. SUTTANAN, N. (2015). The Space under stilt houses in a Thai Social Context: The Transformation to a Main Functional Space

Prefabrication

Upon further studies of "Ruen Thai", climate adaptation is not the only aspect that can benefit "Thai contemporary timber construction system". The concept of prefabrication has also been utilized by Thai vernacular architecture. This practice is developed from the need to relocate these houses throughout its life cycle. Expansion and modification of the house was also common for "Ruen Thai" and supported by this prefabrication. Wooden joineries are used to facilitate the process of disassembly for these houses. In this type of architecture, the pre-assembled elements are roof frames and wall panels, gable walls included. The primary construction and finishing are not prefabricated. The choice of prefabricated elements came from the limitation of traditional transportation and can only allowed transport of smaller building components.

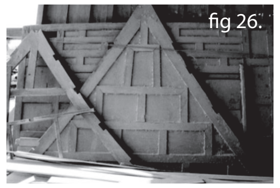
Another notable aspect of Thai vernacular architecture is its frame construction. This aspect does not seem to be inherently important to this project, since there are other suitable construction types in contemporary timber buildings that can be equally functional for "Thai contemporary timber construction system". Nonetheless, frame construction is a crucial part of Thai vernacular architecture's identity and the continuation of this craft depends on the resource of large-dimension timber which is required for its primary structure. The development of wood glue enables the production of larger dimension timbers from smaller trees and these products are commonly used in European timber construction. Importing these timber products allow Thai vernacular architecture to take advantage of these available sources of structural wood elements for their primary structure[29 30].

1. Roof frame

Roof frame are the structural element that are not be fully taken apart when the house is disassembled. The frames are taken down frame by frame and can be easily store or relocate.

2. Wall panel

Walls are preassembled and attached to the structure in the form of panels. They are kept in panel form when the house is dismantled. The pattern can have various design, some of them reflect the structure of the frame itself.

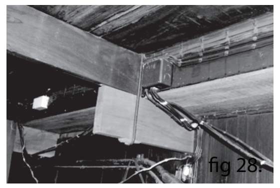


3. Gable wall

Gable wall has the same construction principle as wall panels and will be kept assembled when relocation occured.

4. Main structure

Main structural elements are built out of local hardwood timber. Each element are connected with wood working joints, which aids the disassemble and reassemble processes. Modularity is another concept that were used to facilitate reolcation, expansion and modification.



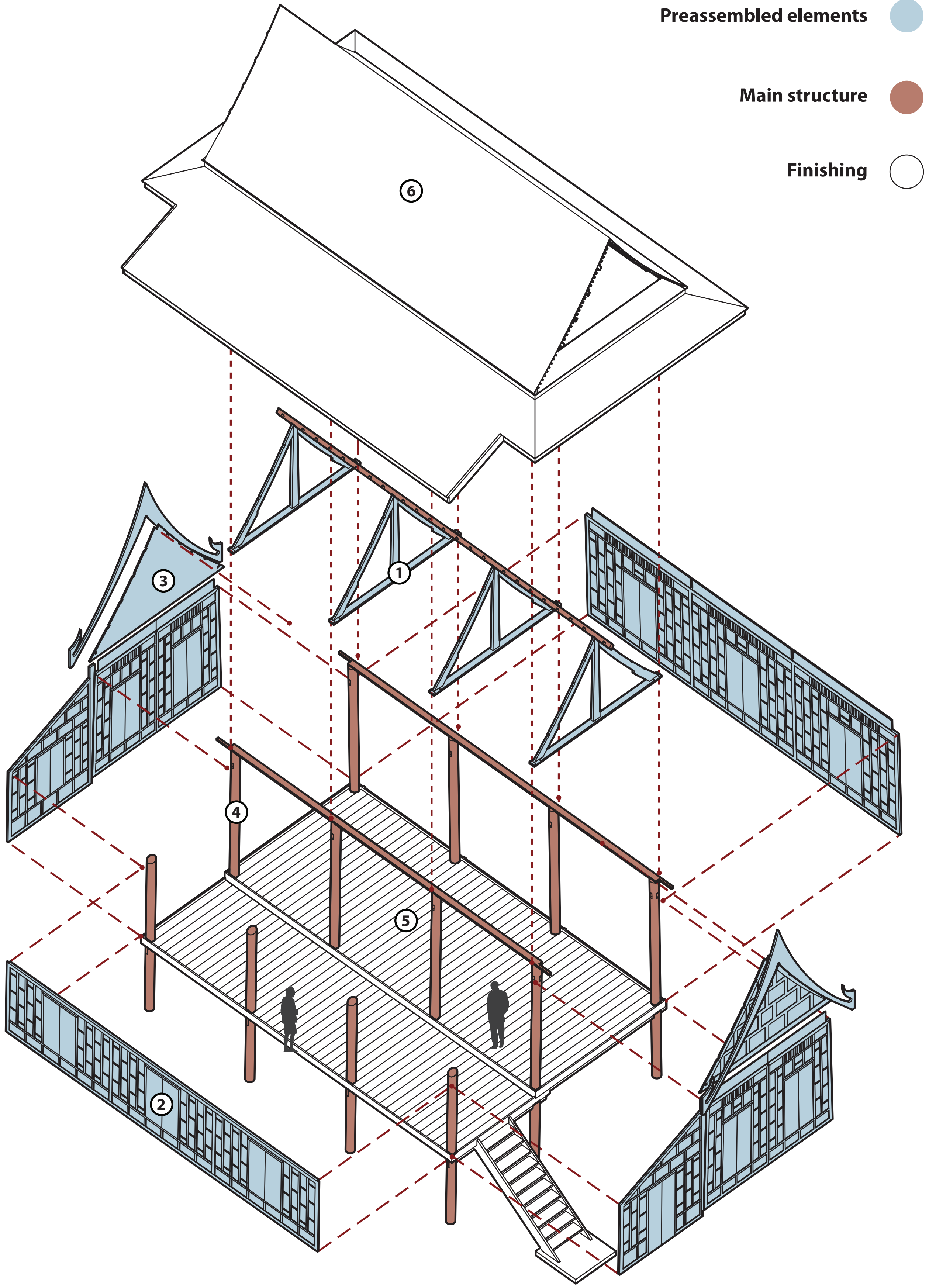
5. Floor finishing

Wood are the main material for floor finishes. Similar to main structural elements, wood working joints are used to combine each elements including floor structure.

6. Roof finishing

Roof finish can be built from many local materials, e.g. thatch or tiles. In modern renovation, other industrialized materials, such as metal sheets, are often used to repair or replace the traditional roofs.

fig 24., fig 25., fig 26., fig 27., fig 28., fig 29. กรมศิลปากร. (2010). โครงการจัดทำองค์ความรู้ด้านการสำรวจสถาปัตยกรรมเพื่อการอนุรักษ์โบราณสถาน (อาคารเรือนทรงไทย)



29. กรมศิลปากร. (2010). โครงการจัดทำองค์ความรู้ด้านการสำรวจสถาปัตยกรรมเพื่อการอนุรักษ์โบราณสถาน (อาคารเรือนทรงไทย)
30. RAMASOOT, S. (2013). Sustainability via Adaptability: Learning from the Traditional Thai House's Built-for-Change Architecture.

Modularity

The concept of modularity has also been employed by Thai vernacular architecture. Modularity was used to create modifiable building that can accommodate growing families and allow relocation of its residences. A single unit can already accommodate one person or a small family. However, Combinations of units can create wide variety of living spaces, which can house more family members along with others functional units. Each single unit can also be joined with other rooms through the central terraces. This creates the possibility of flexible expansion of "Ruen Thai" through numerous combinations[30].

1. Room units

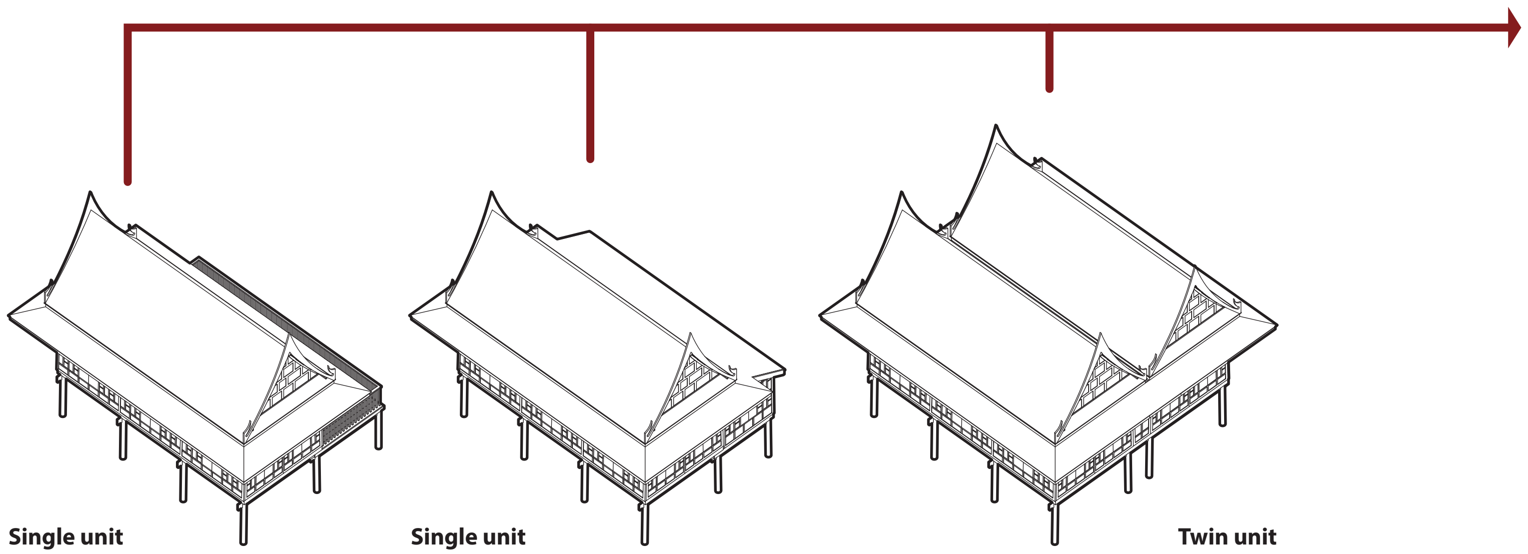
Another distinct spatial attribute of Thai vernacular house is the room units. One function in Thai house will occupy a single unit. For example, each family member can have their own room unit, while the kitchen unit is a separate entity locates further away. All of these units are connected through the central terrace. When a new member joins a family, new unit can be built, or the units that the new member own can be joined to his/her new house. The houses from different region shared the same principle and can be integrated into a single building.

2. Veranda, porch

Some of the larger room units can be equipped with a veranda or porch. This space is used as auxiliary spaces for the unit itself or the central terrace or both. Verandas or porches are always covered with roof. Some of this space can be covered with walls on all four sides or can be fully open to the central terrace.

3. Central terrace

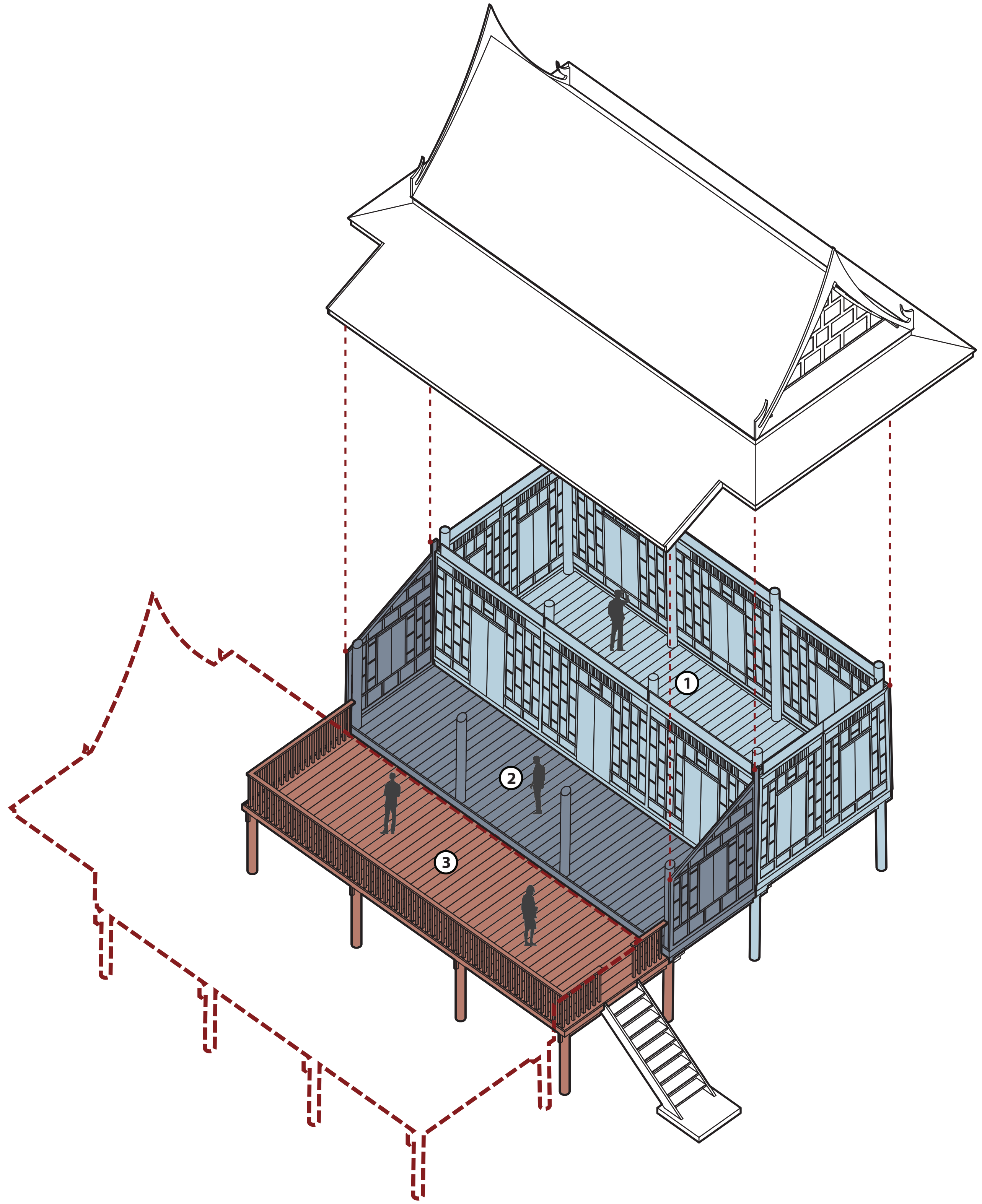
Central terrace is one of the most important and recognizable elements of Thai vernacular architecture. This terrace serves as the main common area shared among its residents. Central terrace usually has no roof. However, in present days, adding roof to an existing old Thai house is a common practice. In the house with several room units, central terrace performs as the core circulation of the house and each unit is accessible through this element. The house can only be access through this terrace. When additional units are added to the existing house, they will be joined through the central terraces. In a large-scale extension, the central terrace itself can be expanded using the same modular unit as the existing one.



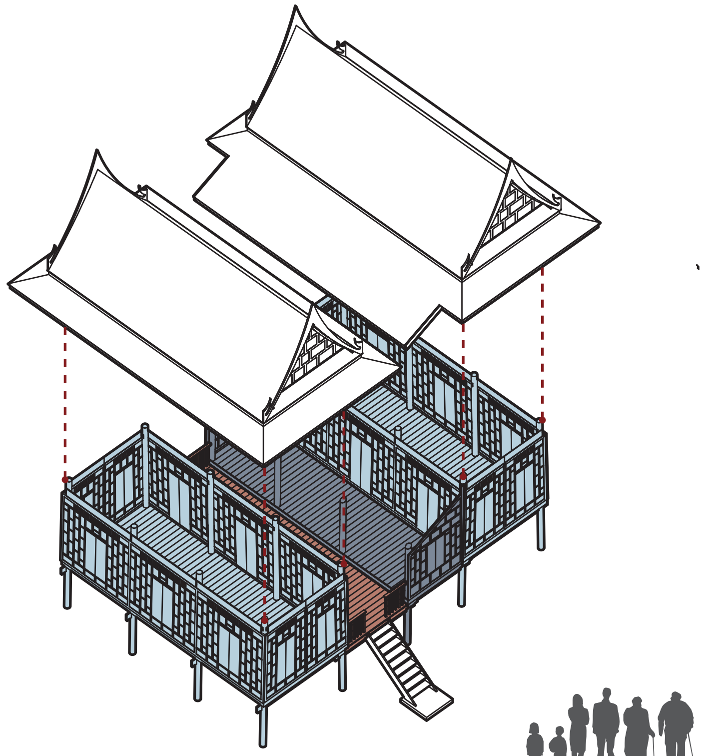
Single unit with extended terrace

Single unit with porch

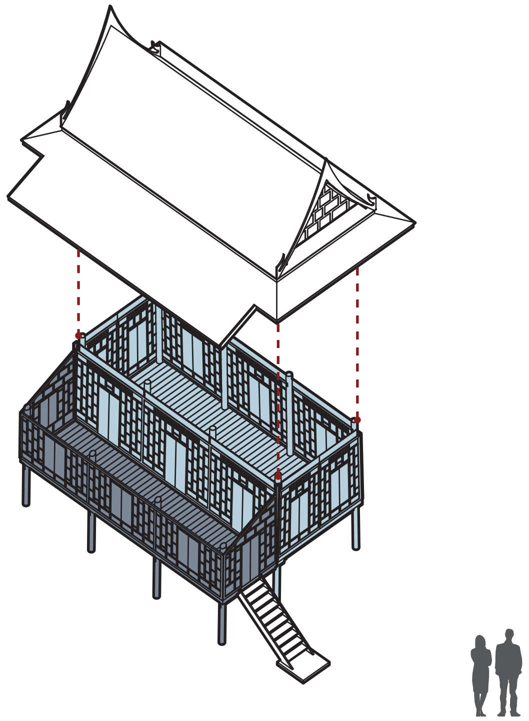
Twin unit



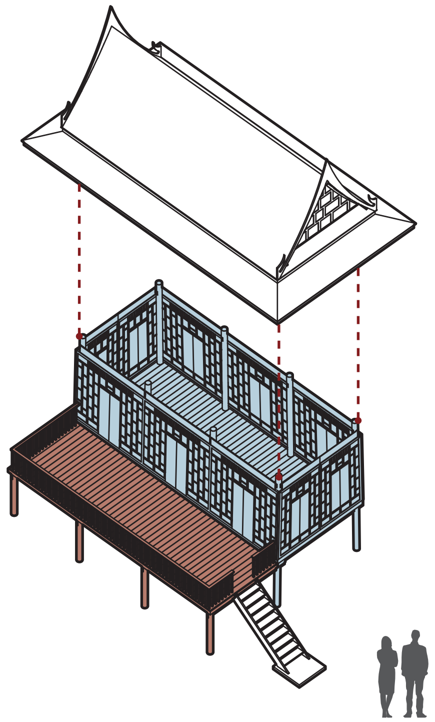
30. RAMASOOT, S. (2013). Sustainability via Adaptability: Learning from the Traditional Thai House's Built-for-Change Architecture.



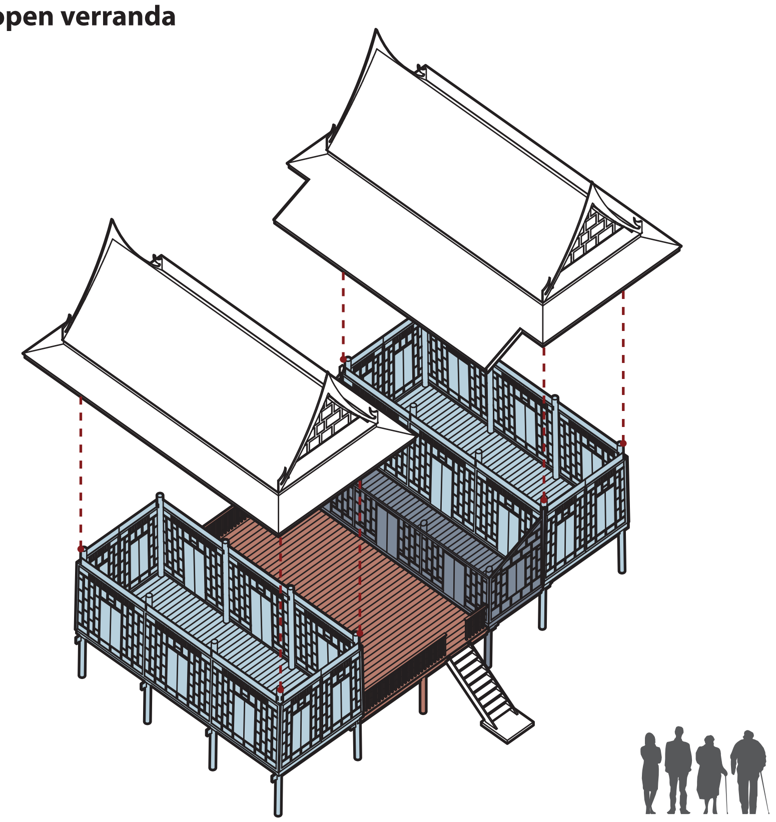
Two single units connected by a terrace, with open verranda



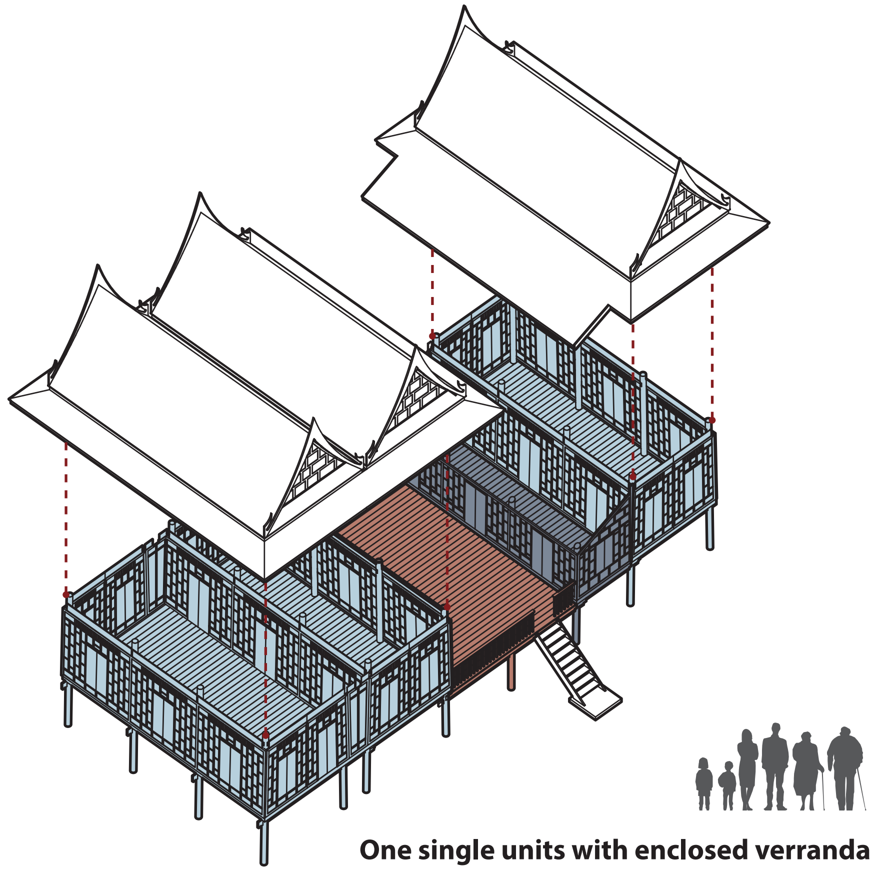
Single unit with enclosed verranda



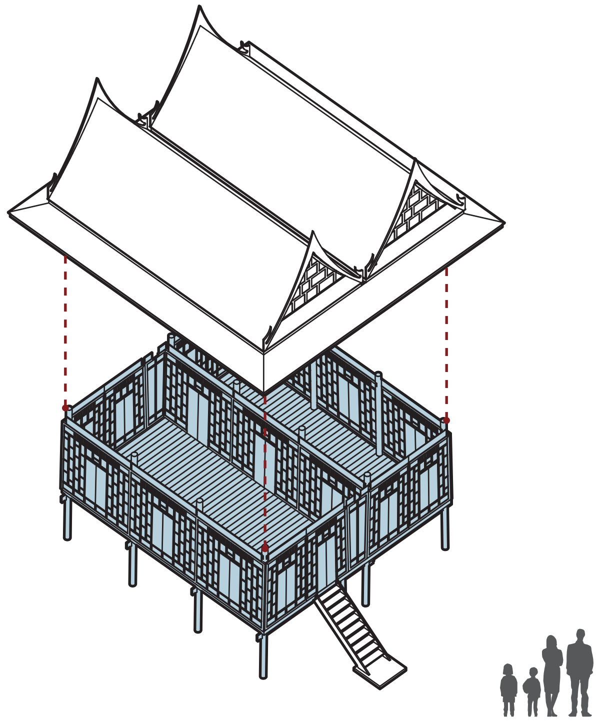
Single unit with terrace



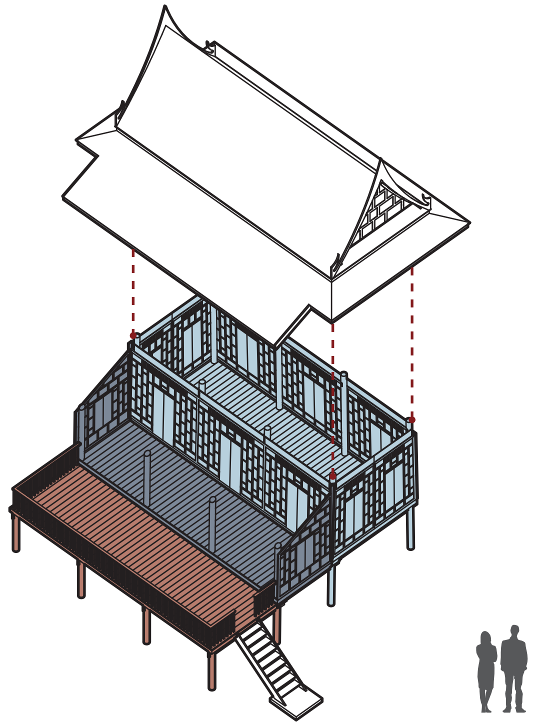
Two single units connected by a larger terrace, with enclosed verranda



One single units with enclosed verranda connected by a larger terrace with a twin unit



Twin unit



Single unit with terrace and open verranda

Units

Veranda or porch

Central terrace

Thai contemporary architecture analysis

Unlike Thai vernacular architecture, Thai contemporary architecture came in all size and form. Putting a frame on this study will be extremely beneficial for this analysis, making it more informative and efficient. The first thing that needs to be established is the number of house type that is going to be analyzed. This number should be corresponding to the number of prototype buildings in this project.

The number of buildings needs to demonstrate the balance of efficiency and flexibility of "Thai contemporary timber construction system" without being too overburden. In my opinion, threes prototype buildings are the minimum number of houses that can still achieve this balance. Two of the houses will be commercial house and the last one will be custom design house. The decision of having two commercial houses is chosen because "Thai contemporary timber construction system" needs to demonstrate its degrees of design adjustments within the scope of replicative architecture. Therefore, these houses need to be a different commercial house type. According to the house type statistic in the previous chapter single detached house and row house are the two most common house types in Thailand. These house types will be the ones I chose for prototype buildings. The custom design house is chosen in order to demonstrate the application of "Thai contemporary timber construction system" outside the scope of commercial house.

Number of floors is another framework that needs to be established. Commercial houses are usually focused on its efficiency, which highly prioritize the size of its land plot. This makes single-storey houses not a favorable choice in commercial project, since it requires more land than multi-storeys house with the same floor area. The number of the floors however, is still limited to two floors by the regulation. A single storey house should also be demonstrated by the design of this project. In this situation, custom design house, which has less concerns for its land plot, is a more suitable choice.

In order to proceed with the analysis of Thai contemporary architecture, the size of the house for this study has to be determined. The size of the house scales with family units. The concept of maximizing impact of this project still apply in this section and the most common family units in Thailand will determine this choice. Based on study by United Nations Population Fund, in the year 2013, the most prevalent family demographic of Thailand out of 19.5 million families are as following[32].

- Family with children and representative from older generation: 33.6%
- Couple with children: 26.6%
- Couple without children: 16.2%

fig 30. Custom Design House

fig 30. Custom Design House - source: Viriyaroj B.

32. Thailand.unfpa.org. (2018). [online] Available at: https://thailand.unfpa.org/sites/default/files/pub-pdf/State%20of%20Thailand%20Population%20report%202015-Thai%20Family_th.pdf [Accessed 21 Oct. 2018].

fig 31. Commercial Row House

fig 32. Commercial Detached House

The functions of the house which can accommodate these three family units are as following.

Family with children and representative from older generation
- 3 bedrooms, 3 bathrooms, 1 kitchen, 1 dining room, 1 living room, 1 study, 1 powder room

Couple with children
- 2 bedrooms, 1 study (or 1 extra bedroom), 2 bathrooms, 1 study, 1 kitchen, 1 dining room, 1 living room, 1 powder room

Couple without children
- 1 bedroom, 1 study (or 1 extra bedroom), 2 bathrooms, 1 study, 1 kitchen, 1 dining room, 1 living room, 1 powder room

House type and number of storeys can then be applied to these family units. The commercial houses favor the smaller scale family. Row house is usually smaller than single detached house and should accommodate a smaller family unit. Single storey custom design house, which has the most flexibility, should accommodate the family unit with the highest number of members. In addition, single storey provide better accessibility for limited mobility people. Therefore, it is a more suitable choice for family with older generations. Based on these reasons, the following list is the final framework for analysis of Thai contemporary architecture and future design of prototype houses.

Two storeys commercial single detached house
Couple with children
- 3 bedrooms, 3 bathrooms, 1 kitchen, 1 dining room, 1 living room, 1 study, 1 powder room

Two storeys commercial row house
Couple without children
- 2 bedrooms, 1 study (or 1 extra bedroom), 2 bathrooms, 1 study, 1 kitchen, 1 dining room, 1 living room, 1 powder room

Single storey custom design house
Family with children and representative from older generation
- 1 bedroom, 1 study (or 1 extra bedroom), 2 bathrooms, 1 study, 1 kitchen, 1 dining room, 1 living room, 1 powder room

fig 31. Commercial Row House - source : Viriyaroj B.
fig 32. Commercial Detached House - source : https://www.lh.co.th/th/singlehome

Two storeys commercial single detached house for couple with children

Size: 180-250 m2
Price: The house in the scale starting price of 90.000€ up to 400.000€, depending on the location and construction costs.

Commercial detached houses are one of the most common residence types in Thailand. In this case study the focus is on the house for family with one or more children, which is one of most widespread family units. The user of this house type mostly based their decision on the combination of price of the product, neighborhood and location. The most prominent criteria for design are the cost of construction. This factor translated to the extreme focus on functional efficiency in its design. Therefore, balancing house area and living quality is the main challenge in this house type.

Unfortunately, climate adaptation for this house type is usually fallen behind in the scale of importance. Because of the duplicative nature of this type of project, building orientation is a less relevant concern. The design of the house comes in many variations, mostly based on marketing research by the real estate companies. Appearance in this house type is highly superficial. Decorative elements are often seen, while architecturally crafted aesthetic is rarely found. This is especially true in the house with lower price range. In order to stand out from their competitor and attract more customers, these projects need to establish its identity and uniqueness. Base on this need for identity, many of these houses have adopted building elements and name from foreign architectural types or well-known locations. This decision frequently ended up with famous touristic spots for Thai people.

Building elements

1. Landplots
- The size of the landplots are determined by the covering area of each house.
- Setback distance from the house is another factor for landplot size, which measure from the outer walls of any functional area to their closest fence.
- For two storeys house the setbacks on the side and the back are 2 metres, and on the front the setback depends on the size of the road (usually 3 metres)

2. Second floor circulation
- In this type of houses the size of circulation on second floor is preferred to be as compact as possible.

3. Balcony
- The roof of the garage can be use as a balcony in some cases.
- Aside from garage roof balcony, balconies for houses are relatively narrow (less than 2 metres).
- Condensing units for air conditioners are almost always placed on the balconies.

4. Living area
- Living area is connected functionally with dining area without partition.
- The first floor circulation is integrated with the functional spaces for efficiency.
- The houses can either have the access directly in to the living area or through an entrance hall or both.

5. Powder room
- It is very common in this type of houses to have powder room on the first floor.
- Sometimes the powder room will be place under the stairs for efficiency of space.

6. Bathroom
- Bathrooms are designed to be very compact.
- The main criteria is to have as many fixtures as possible in the smallest area.

7. Bedrooms
- Working space or television with sofa are frequently seen functions in the bedrooms.
- Existence of master bedroom is a prevalent concept in contemporary houses.

8. Kitchen
- One small kitchen is commonly provided inside the house next to the dining side of living area.
- In some house another proper kitchen, without walls, is frequently placed outside of the house with connecting structure.
- Additional kitchen can be provide presale or added as an extension by the owners.

9. Storage
- Space under the stairs is often utillized as storage space or toilet.
- External storage is common and it can be access from the garage

10. Garage
- Cars are almost required in every household.
- Garages often have no walls but with roof covered.
They are attached to the house.

11. Roof
- Hip roof is the most common form of roof in this type of house, followed by gable roof.
- The eaves of the roof are not prolonged in most cases, for a lower construction cost.

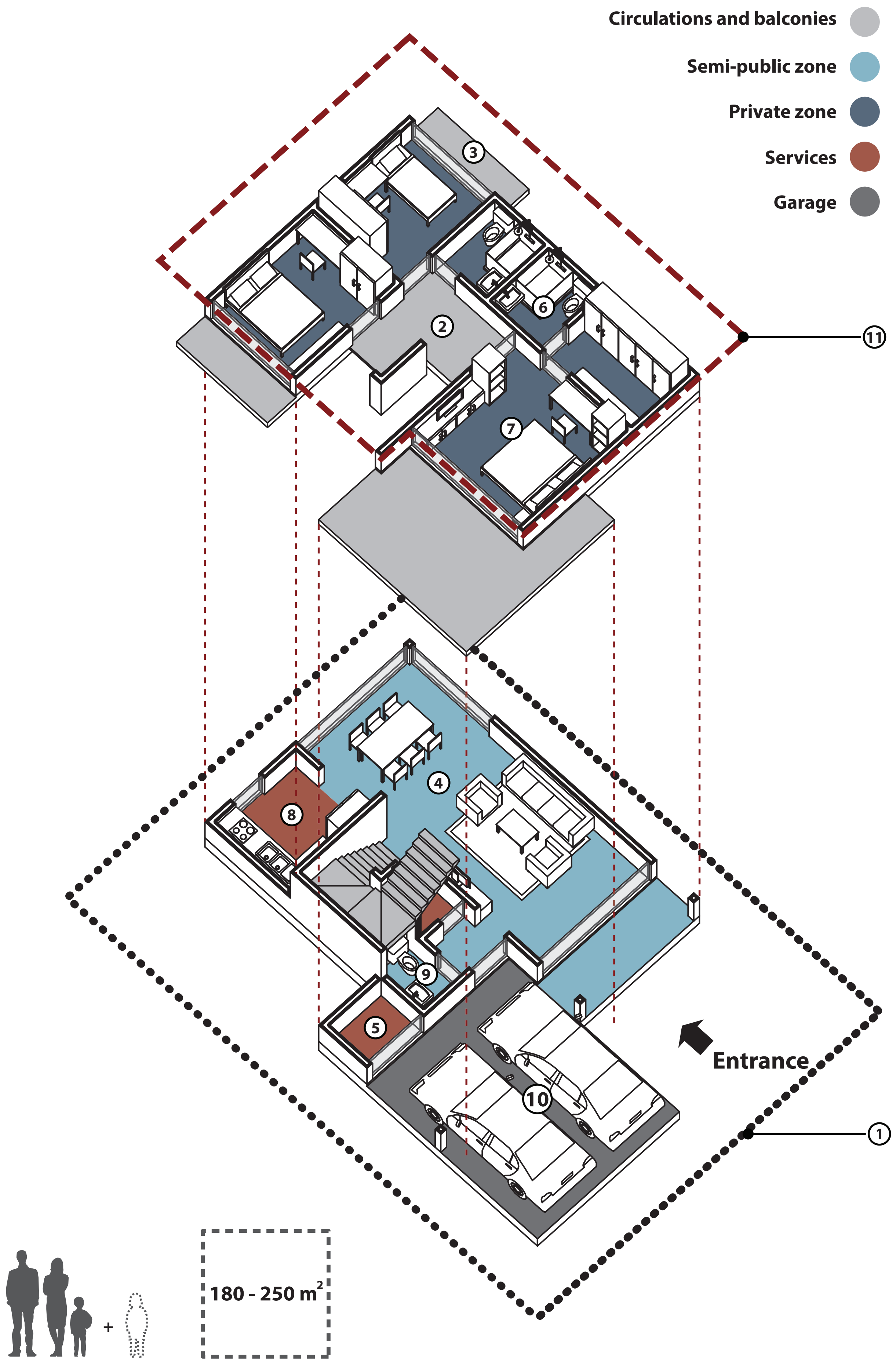
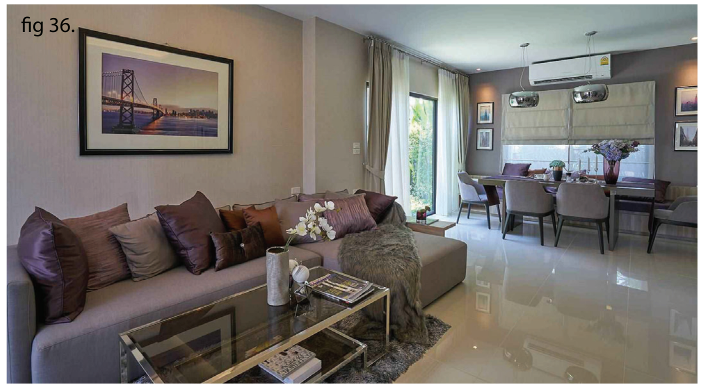



fig 33.


fig 34.


fig 35.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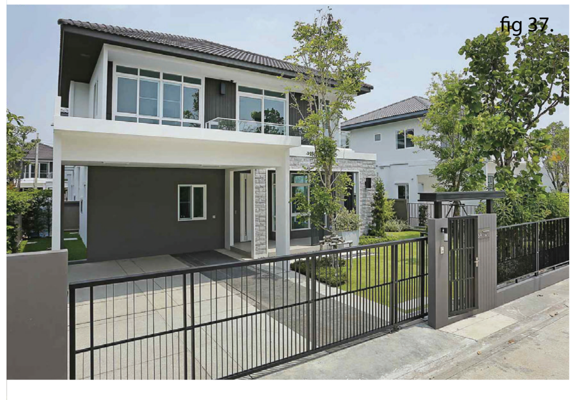


fig 37.


fig 38.


fig 39.


fig 40.

Commercial Detached House
fig 33., fig 34., fig 35., fig 36., fig 37., fig 38. source : https://www.lh.co.th/th/singlehome [Accessed 24 Oct. 2018].,


fig 41.


fig 42.


fig 43.


fig 44.


fig 45.


fig 46.


fig 47.


fig 48.

fig 39., fig 40., fig 41., fig 42. source : https://www.sansiri.com/en/singlehouse [Accessed 24 Oct. 2018].
fig 43., fig 44., fig 45., fig 46. fig 47., fig 48. source : https://www.pruksa.com/single-detach-house#goto-list-search [Accessed 24 Oct. 2018].,

Two storeys commercial row house for couple without children

Size: 180-250 m2
Price: The house in this case study has starting price of 32.000€ up to 150.000€, depending on th location and size.

Commercial row houses are commonly built in the area with higher land value. This result in, row house project usually has higher price per usable area than detached houses. In this case study, the choice of the house scale is based on family size. Family of parents without child is the third most common family unit and the chosen family type. Commercial row houses are very similar to detached houses in term of design principals. Efficiency and economic factors are two most important factors for every project. However, row-house has an additional factor of having only two facades, which means that the organization of functional areas are more restricted. Similar to commercial detached house, recognizable appearance is still a prevalent design criteria, while sophisticated architectural aesthetic and climate adaptation are less concerned.

Building elements

1. Second floor circulation
- Size of circulation on second floor is preferred to be as modest as possible.

2. Stairs
- Stairs are design with highest efficiency in mind.
- Space under the stairs is often utillized as storage space or toilet.

3. Balcony
- The roof of the garage can be use as a balcony in some cases.
- Aside from garage roof balcony, balconies for houses are relatively narrow (less than 2 metres).
- Condensing units for air conditioners are almost always placed on the balconies.

4. Living area
- Living area is connected functionally with dining area without partition.
- The first floor circulation is integrated with the functional space for functional efficiency.
- Users access the house from the living area in most case.

5. Powder room
- It is very common in this type of houses to have powder room on the first floor.
- Sometimes the powder room will be place under the stairs for efficiency.

6. Bedrooms
- Working space or television with sofa are frequently seen functions in the bedrooms.
- Existence of master bedroom is a prevalent concept in contemporary houses.

7. Bathroom
- Bathrooms are designed to be very compact.
- The main criteria is to have as many fixtures as possible in the smallest area.
- Master bedroom usually has en suite bathroom, while other bedrooms has shared bathroom.

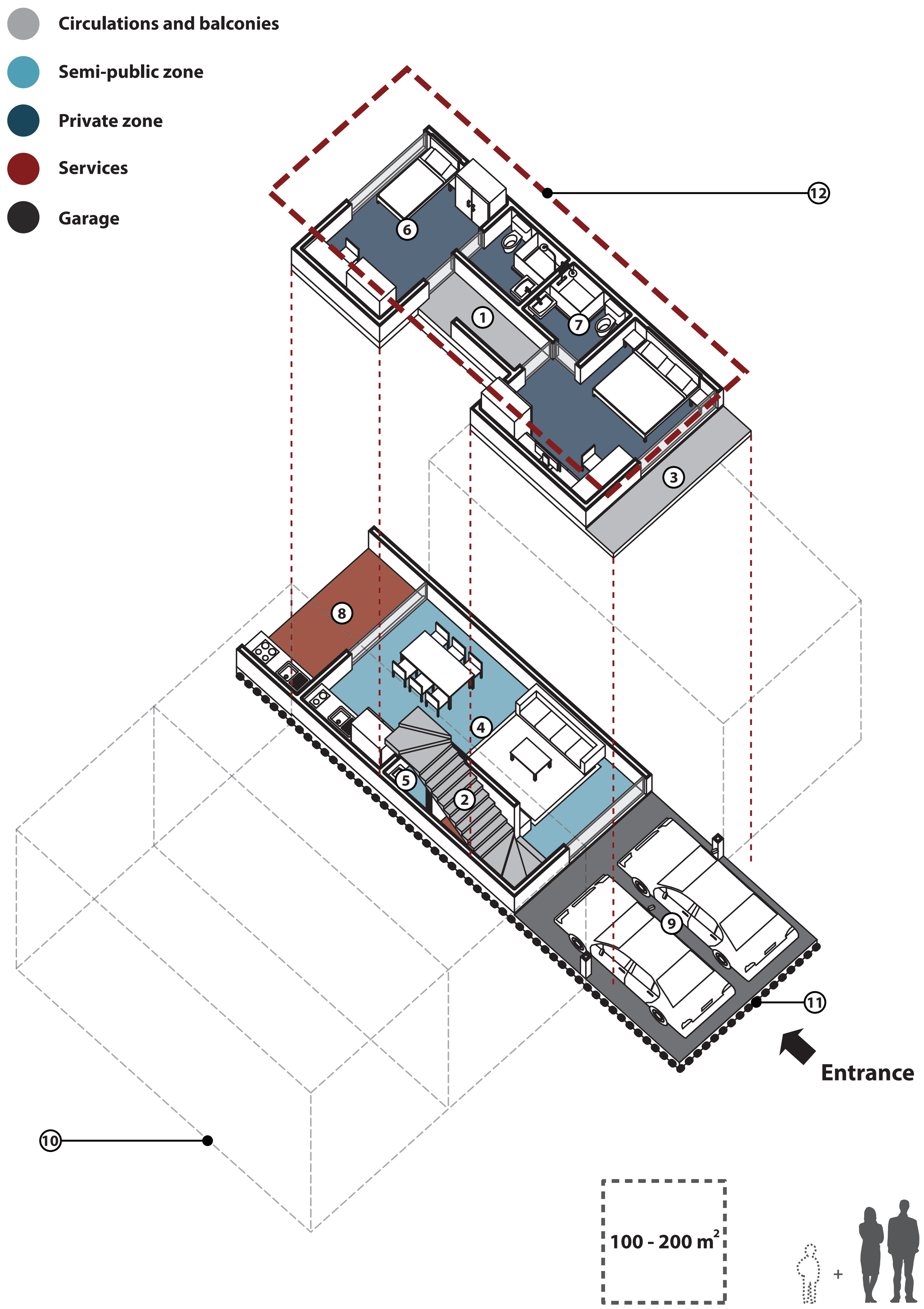
8. Kitchen
- One small kitchen is commonly provided inside the house next to the dining side of living area.
- Setback areas at the back of each house is frequently utillized as an additional kitchen, despite the fact that it is forbidden by the regulation and meant to be left open for fire escape purpose.

9. Garage
- Cars are almost required in every household.
- Garages often have no walls but with roof covered.

10. Adjacent units
- Connecting walls between each unit have to be built with fire-resistance material or combination of material that has equal fire protection attribute.
- Every connected series of units need to have four metres open space break.
- Maximum length of connected units is forty metres. The width of each units is dictated by this regulation to achieve maximum number of units in each row.
- Preferable units widths are the one that are dividable number or closest to dividable number of forty, i.e. 5x8 = 40, 4x10 = 40, 4,4 x 9 = 39,6.

11. Landplots
- The size of the landplots are determined by the covering area of each house.
- Setback distance from the house is another factor for landplot size, which measure from the outer walls of any functional area to their closest fence.
- For two storeys house the setbacks on the side and the back are 2 metres, and on the front the setback depends on the size of the road (usually 3 metres)
- There is a minimum width of the landplot and the house in the regulation. The minimum width is four metres.

12. Roof
- The common roof form in this house type are one-pitched roof, hip roof and gable roof.
- The eaves of the roof are less extended in most case, to save construction cost.



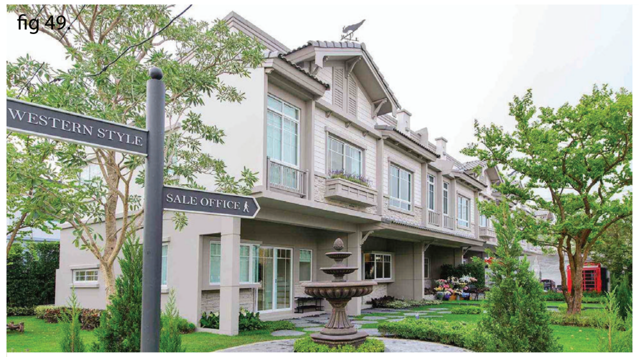


fig 49.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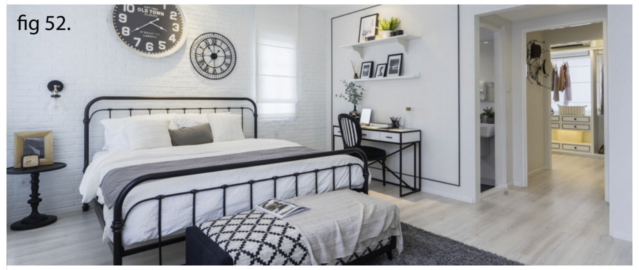


fig 52.


fig 53.


fig 54.

fig 55.


fig 56.

fig 57.

Commercial Row House
fig 49., fig 50., fig 51., fig 52. source : https://www.lh.co.th/th/townhome [Accessed 24 Oct. 2018].,


fig 58.

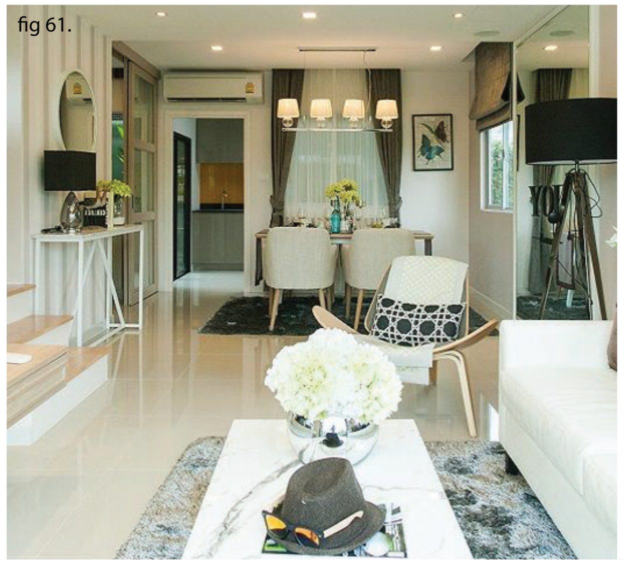
fig 62.


fig 59.


fig 63.


fig 60.


fig 64.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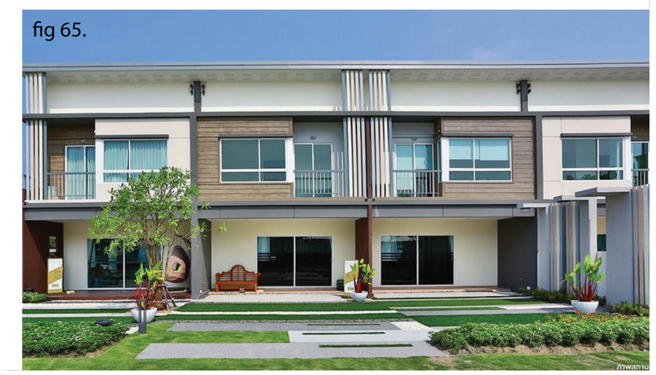


fig 65.

fig 53., fig 60., fig 61., fig 63., fig 64., fig 65. source : https://www.pruksa.com/townhouse#goto-list-search [Accessed 24 Oct. 2018].
fig 52., fig 55., fig 56., fig 58., fig 59., fig 62. source: https://www.sansiri.com/en/townhouse [Accessed 24 Oct. 2018].

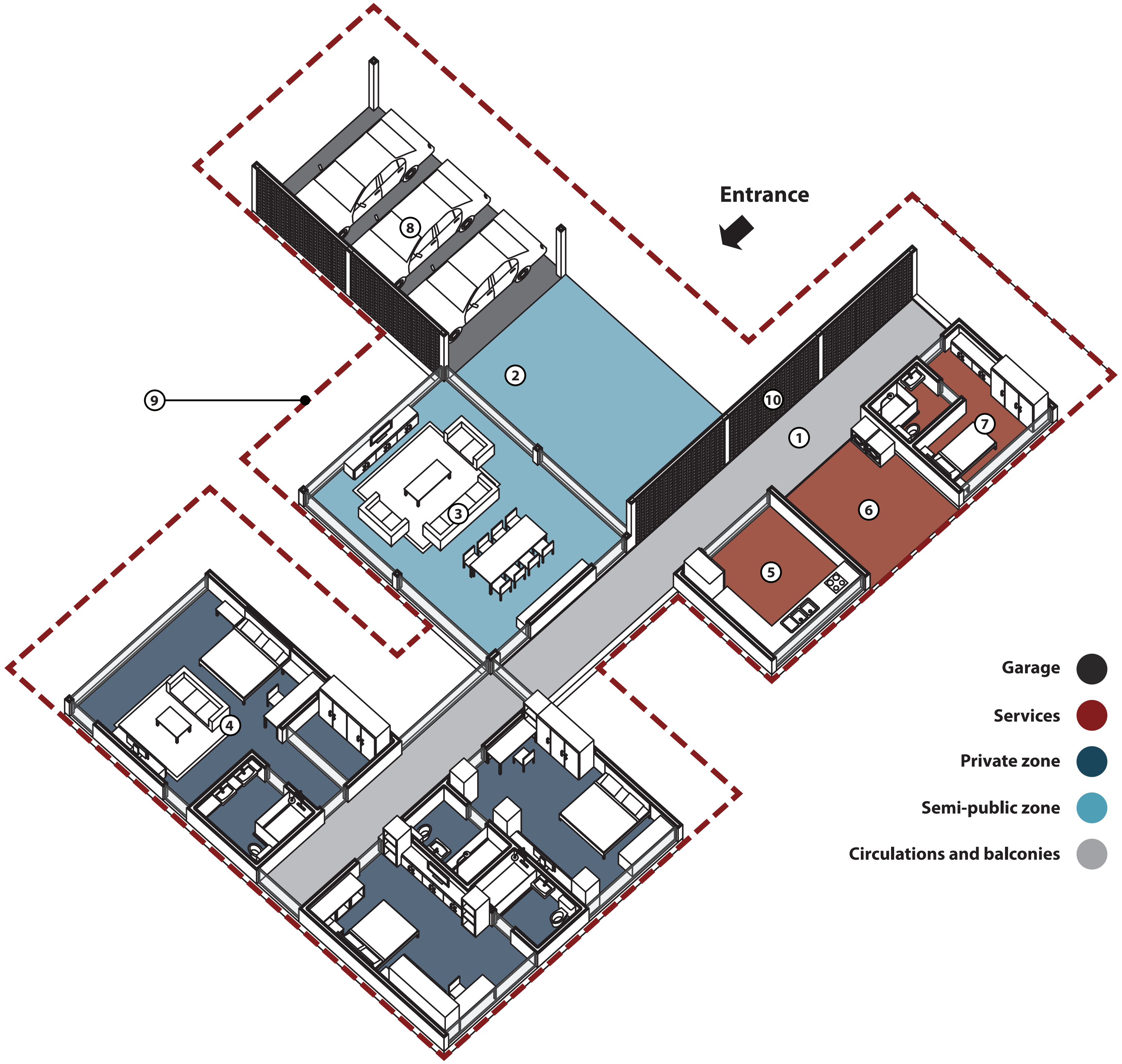
Single storeys custom design house for family with children and representative from older generation

Size: more than 200 m2

Price: Price of custom design house depends on its size. The construction cost per square meter of this house type starts from 450€.

Single storey custom design houses are usually design by architects. They are often own by Upper class to Upper middle-class families. Price of the land plot have prominent effect in the ownership of one storey houses, since they require larger site area than the multi-storeys one. Security is another concern for owning this type of houses. Since, they have more ground level openings, they are considered more vulnerable and less private. Therefore, single storey houses are often situated in less urban area or in a larger site with room for vegetations. The leading reason for people to choose one storey houses is its accessibility by people with limited mobility. This means that, families with older generations or wheelchair bound members are more likely to choose single storey houses than other family units.

Modernist architecture used to be a dominant style in housing design for Thai architects in late 20th century and early 21st century. However, in recent years, design approaches for residential buildings by Thai architects have started to shift away from Modernist architecture. The root of Thai architecture has started to become the focal point of house design. Integration of contemporary houses and vernacular house has been increasingly adopted as design principle by Thai architects. Connections with outdoor environment either physically or visually are common features in contemporary Thai houses, especially in single storey houses.



1. Circulation
- A lot of design consideration is often put in to circulation of custom design house and can a focal point of design in some.
- Outdoor circulation can be preferable in some building designs.

2. Entrance hall
- Entrance hall are common and can be in the form of both indoor or outdoor.

3. Main living space
- Living area also used to accomodate guests. Open plan and combination of living room and dining room are common in custom design houses.

4. Bedrooms
- Working space or television with sofa are frequently seen functions in the bedrooms.
- Bedrooms in customized design houses are commonly equip with en suit bathroom, sometimes with walk-in closet.
- Master bedroom is a prevalent concept in contemporary houses.

5. Kitchen
- Kitchen is frequently detached from the living area. In some cases, it is detached from the dining area, which will be equipped with a pantry.
- Thai kitchen is usually built as a separate rooms, sometimes without walls but mostly with roof covered.
- If a house has a kitchen that is separate from other functions it does not need to be an outdoor kitchen

6. Washing area, Laundry area
- Washing or laundry area are often outdoor, regardless of the method for washing (with roof covered for machine).
- For outdoor washing area, the clothes are dry by the sun without using machines.

7. Maid room
- In some houses of wealthy owners, maid's room can be design as part of the house.
- These room can be use for maids as working space, rest area or for overnight stays.

8. Garage
- Cars are almost required in every household.
- Garages usually has roof but without walls. They can be detached from the house.

9. Roof
- Extended eaves is a solution that has been widely use to protect indoor area from heating up by the sun.
- Roof can comes in many form, the most common ones in contemporary architectures are flat roof, single- pitch roof, gable roof and hip roof.

10. Perforated elements
- Perforated elements are often use to create visual barriers, common materials for these elements are woods, steels or bricks.

fig 66. source : https://dsignsomething.com/2018/06/07/บ้านสวย-ทีเลือกปีดและเ/

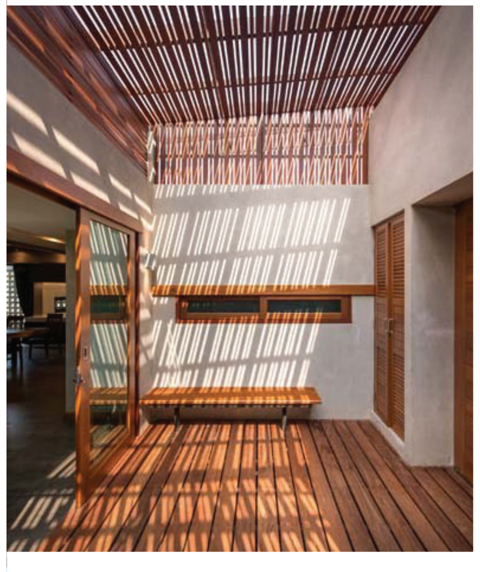


fig 67. source : https://dsignsomething.com/2018/03/29/พักใจทีบ้านแห่งความสม/

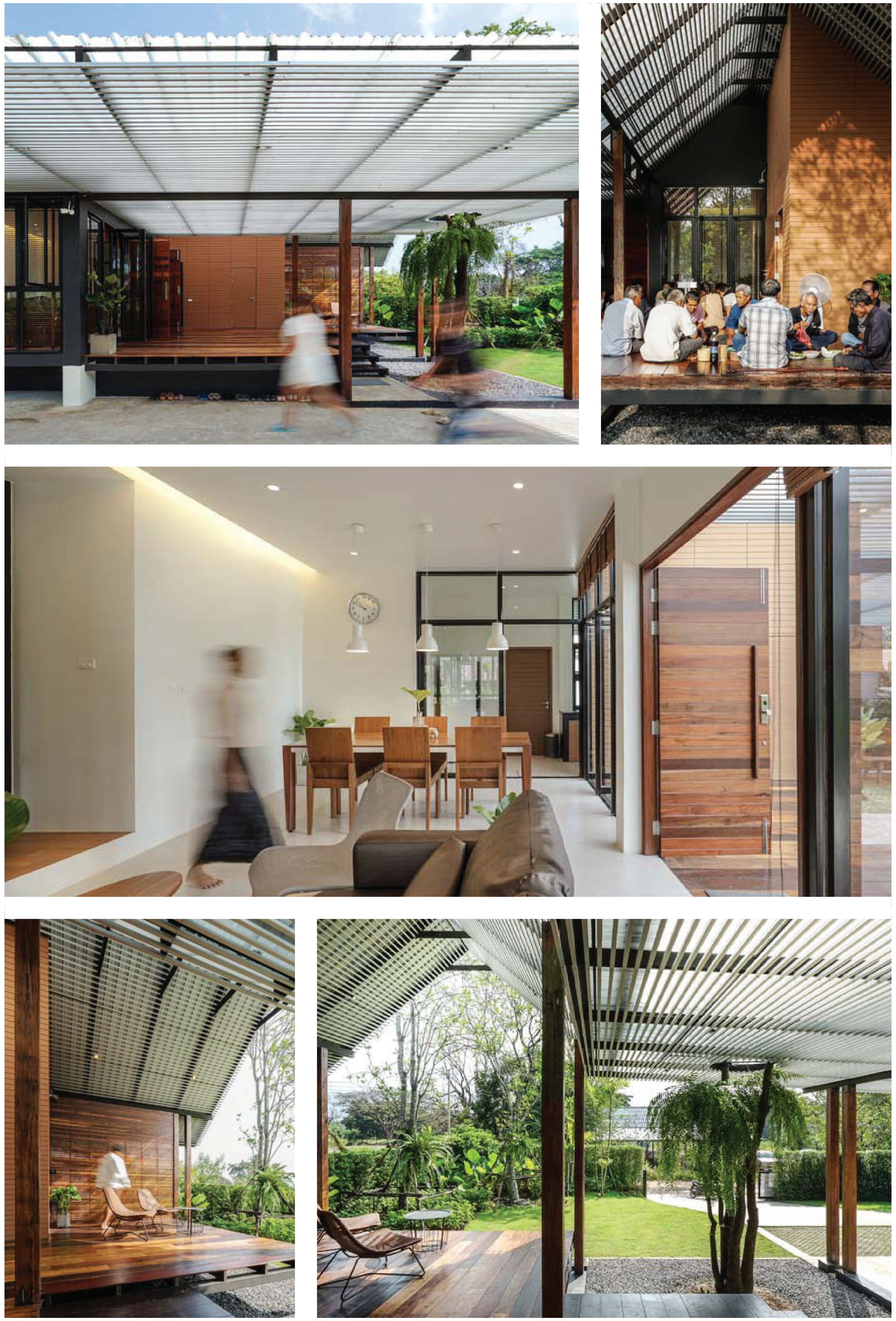


fig 68. source : https://dsignsomething.com/2017/12/28/โฮมบุญ-บ้านทีเกิดจากวิ/

fig 69. Thai Timber Frame Construction

fig 70. Contemporary Timber Frame Construction

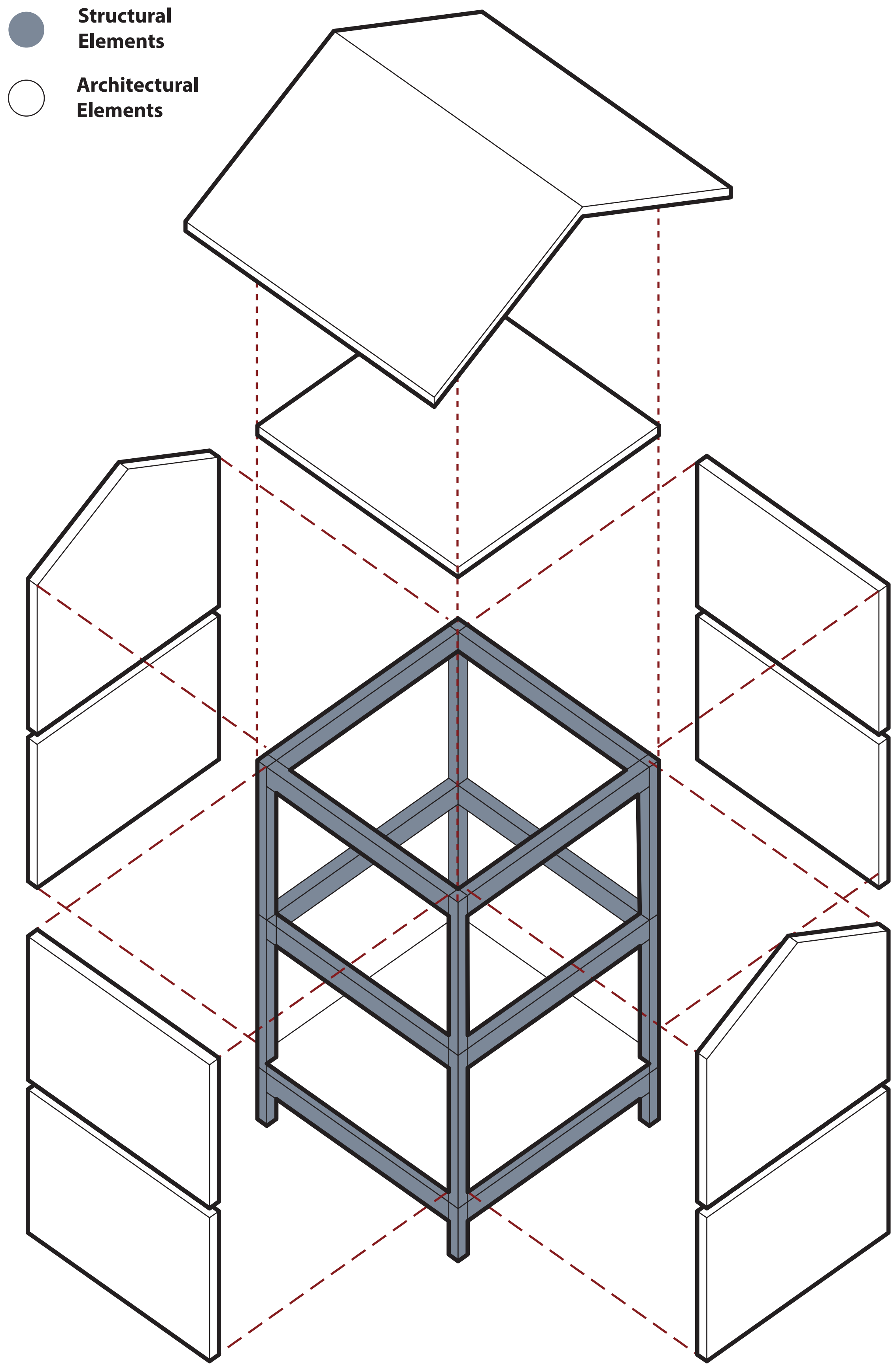
European timber construction analysis

Frame construction

Construction type is the subject that can be studied from developed timber construction knowledge in European countries. Among various construction types, frame construction has attributes that fit the most with the goal and context of this thesis. Extensive design freedom of frame construction allowed Thai architect to utilized "Thai contemporary timber construction system" in the way they envisioned. A stricter construction system would reduce the level of engagement Thai architect can have with "Thai contemporary timber construction system", thus remove them of their possibility to learn timber construction through this system[17].

The context of Thai construction industry is also more compatible with frame construction than other construction types. Frame construction is the staple practice for contemporary Thai builders, which has been used extensively in Thai concrete construction. Some level of obstacle for learning timber construction can be removed for Thai builders, by allowing their understanding of load-bearing concept to be used in this new construction system. Thai vernacular architecture can also benefit from choosing frame construction. It has already been previously mentioned that frame construction is a core characteristic of Thai vernacular architecture[29]. Thai vernacular architecture needs large dimension timber for their frame structure, and the additional source of glue wood products that will be use in contemporary timber buildings can also be use in Thai vernacular houses as well. This give frame construction an edge over other timber construction types and will be the chosen construction type for "Thai contemporary timber construction system".

fig 69. Thai Timber Frame Construction - source : https://www.sanook.com/news/7480830/
fig 70. Contemporary Timber Frame Construction - source : https://tidewatertimberframes.com/timber-frame-construction/



17. KOLB, J. (2008). Systems in Timber Engineering

Enveloping element

1. Plywood
9mm.thickness,
300x120mm.

2. Chipped wood board
12mm. thickness,
300x120mm.

3. Sawn wood plank
25mm. thickness,
100mm. width

4. Sawn wood studs
150x50mm.

5. Sawn wood studs
50x25mm.

6. Mineral wool

7. Glulam beam
315x140mm.

8. Roof truss
140x90mm.

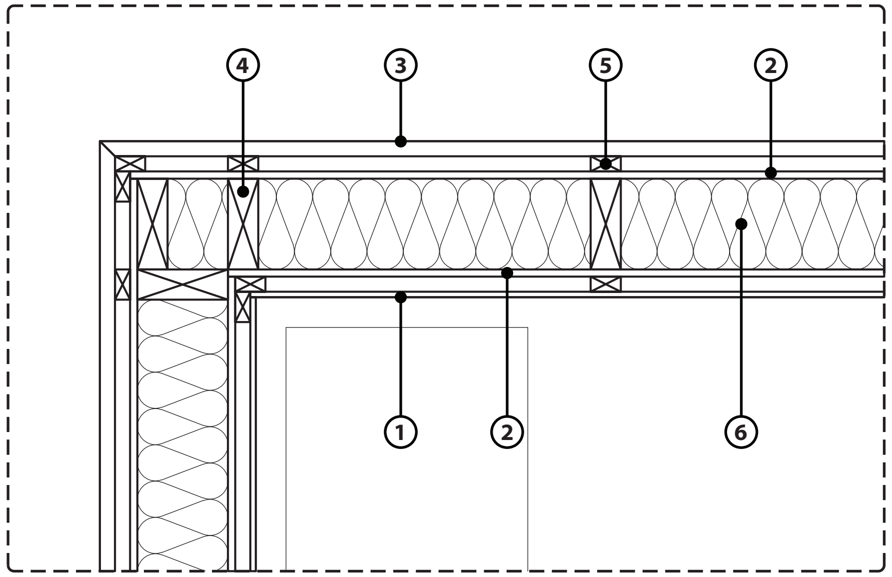
9. Steel sheet roof 1,25mm.
thickness

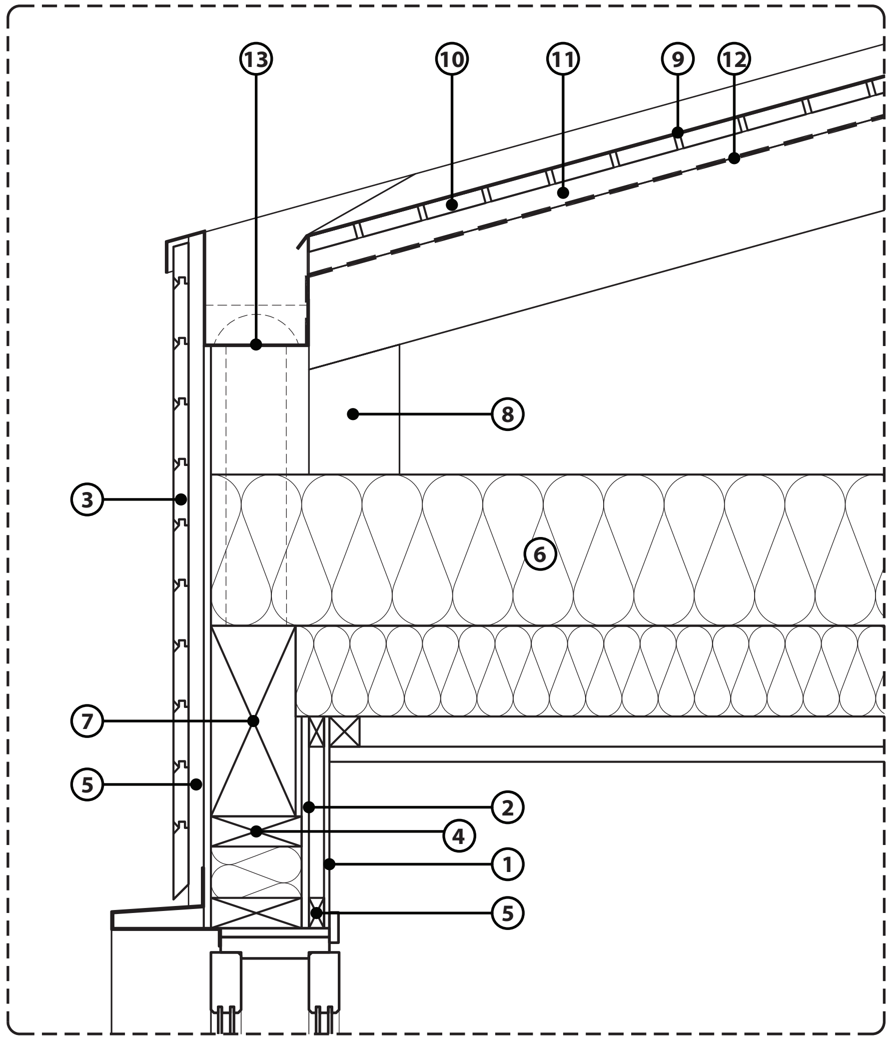
10. Wood board roof
100x25mm.

11. Sawn wood purlin
75x75mm.

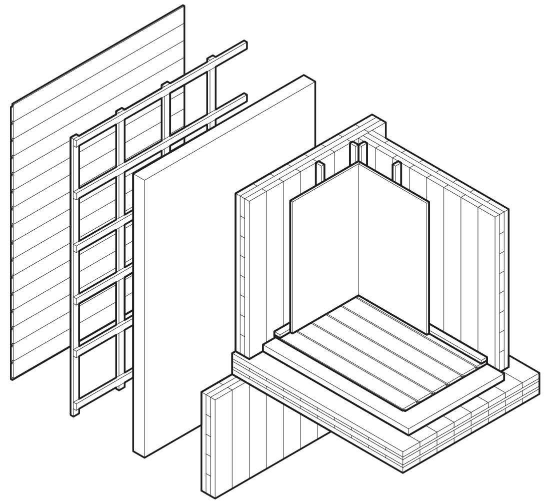
12. Roofing membrane

13. Steel sheet roof drain
1,25mm. thickness,
50mm. width





Example of Building Detail in Timber Construction **scale 1:12.5**



Layers in Building Envelopment

fig 71. Brick Wall in Thailand

Enveloping element

The knowledge that this section will be focus on is the enveloping elements in European timber construction, since this is the knowledge which is missing in timber construction of Thailand[17]. In the current Thai construction industry, the enveloping elements is extremely lacking in the concept of layering, regardless of construction types. In Thai vernacular architecture, the wall consists of one or two layers of panel, these layers are exterior panel in single layer wall and interior panel is included in two layers configuration. The roofs also have similar concept, with roof finishing the only protective layer for building structure. Floor of these buildings is protected from the environment with single layer of plank and nothing else.

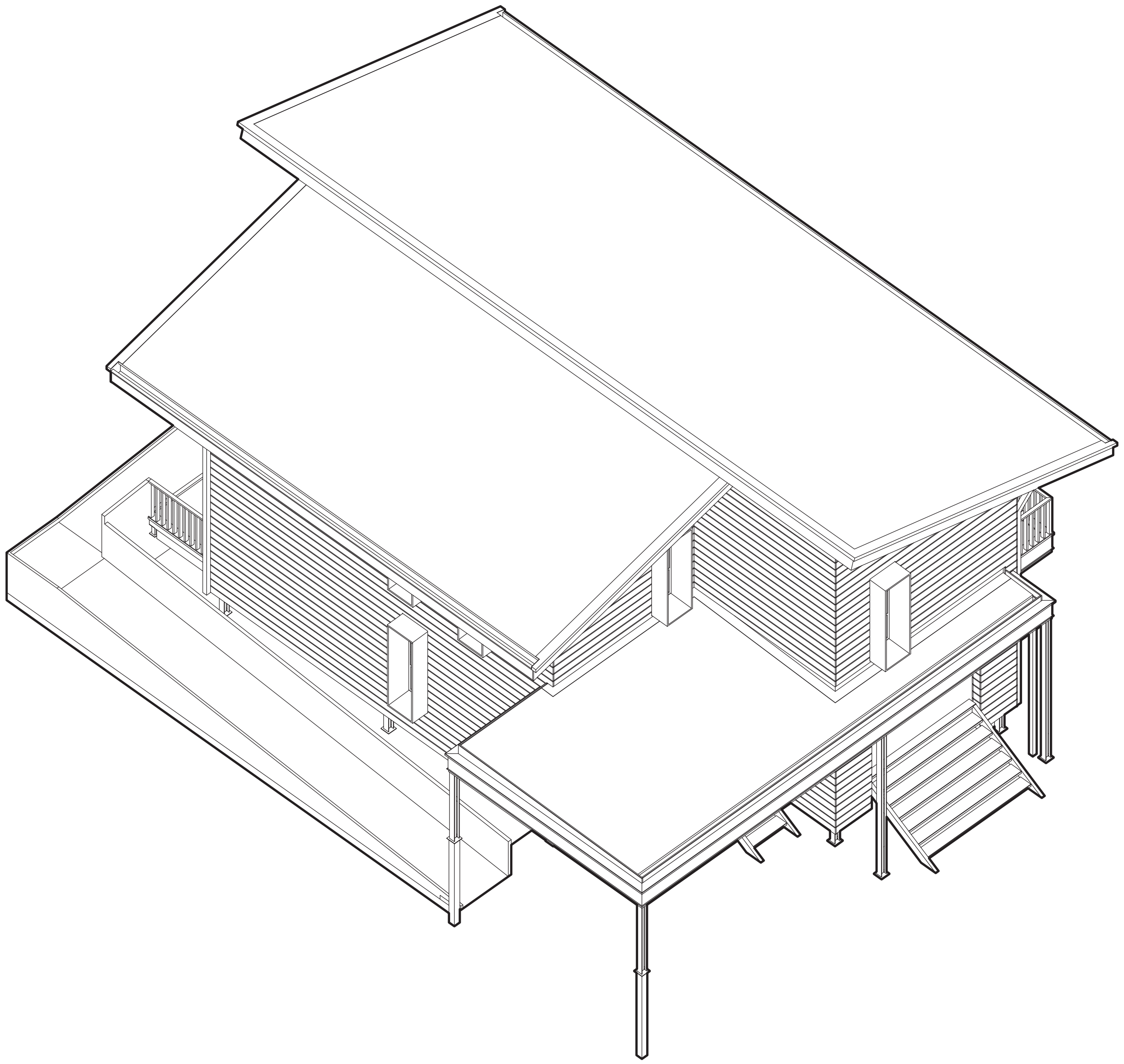
In the context of Thai climate and living standard of traditional lifestyle, these enveloping elements has sufficient temperature protection to the indoor space. However, they do not protect interior space and structural elements from moisture, which is an important aspect that has to be addressed in "Thai contemporary timber construction system". As for the reason that Thai vernacular architecture overlooks the threat of moisture, perhaps the source of wood was abundant or Thai local wood can handle this problem exceptionally well. In the case of the latter reason, this project needs to carefully consider more intricate solutions to the problem of moisture, because the effect of Thai climate on European softwood is still uncertain. The subject of layering and moisture protection can be handled by studying European timber construction[7].

This underutilization of layering persists commonly in contemporary buildings of Thailand. Almost all of the Thai conventional buildings, especially the low-cost houses, has single layer element on walls, floors and roofs. In a house with higher budget, insulation might be added under the roof or, in a rare case, walls. Those are the furthest attempt at the concept of layering for regular houses in Thailand. In recent years, there is an emergence of layering for roof elements, which includes board components, vapour barrier membranes and other sub-structure elements. Nonetheless, these details are developed and sold by roofing material companies. They are developed in a way that capitalized the use of their products and will be sold as a package of roofing solution. This decision definitely has positive affect on the performance of these roofing components. However, it also diminishes the possibility of incorporating this layering concept to other houses without using this whole packaged solution. Moreover, these enveloping elements are design based on steel structure. From these reasons, it is still relevant to study the enveloping elements of European timber construction and incorporate it in to the design of this project.

fig 71. Brick Wall in Thailand - source : https://www.scgbuildingmaterials.com/th/LivingIdea/NewBuild/Half-Brick-Wall.aspx
17. KOLB, J. (2008). Systems in Timber Engineering

fig 72. Thai Local Timber - source: Viriyaroj B.

V. Design of "Thai contemporary timber construction system"

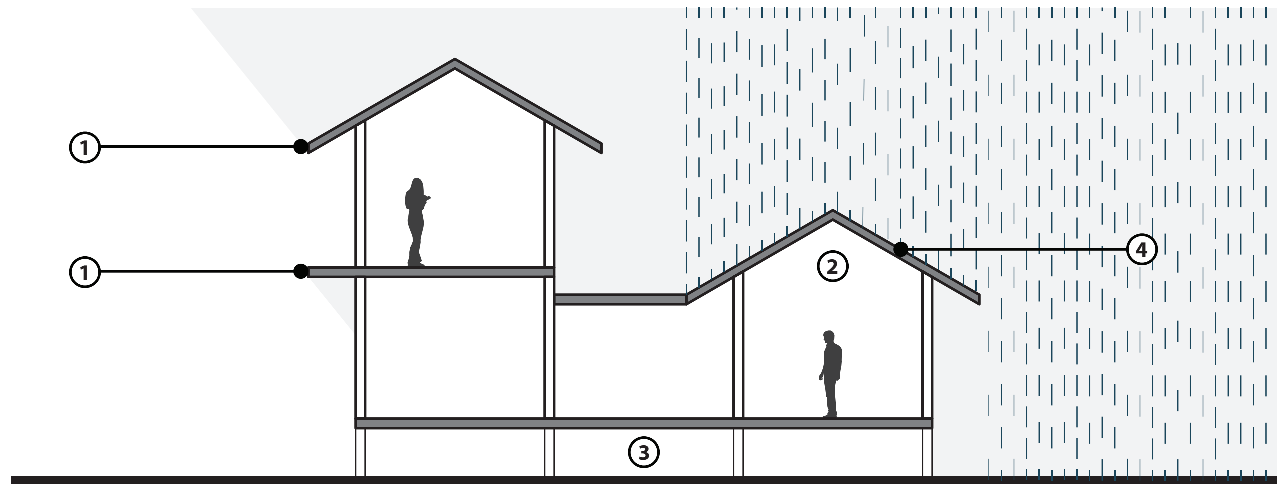


Design of "Thai contemporary timber construction system"

The basis of system design came from the crystalized knowledge that has been gathered throughout the previous processes of this thesis. The purpose of this system, is to perform as a construction standard or guideline for Thai contemporary timber construction and will be used in the design of prototype building in this thesis. In the case of prototype building, the building designs will strictly adhere to the rules of "Thai contemporary timber construction system". However, the system should be able to perform outside of the prototype houses and will be encourage for its utilization by any timber construction project in Thailand. In the case of other Thai timber construction, the degree of adoption will depend on the circumstance of the project and interests of the stakeholders. Partially adoption of this system is strongly recommended, since it will allow the system to grow organically from the process of its application.

Climate adaptation

Climate adaptation in "Thai contemporary timber construction system" will be based on Thai vernacular architecture. There are several prominent elements of climate adaptation in Thai vernacular architecture, which have already been analyzed in the previous chapter. However, further adjustments are needed, in order to utilize these elements properly in the scope of contemporary architecture.



Horizontal Shading and eaves

Shading elements in Thai vernacular respond to the sun condition in Thailand, and can be easily translated in to contemporary architecture. However, eaves only protect the floor directly under the roof. This problem has no effect in Thai vernacular architecture, since it is a strictly one storey building. For multiple storey building in contemporary architecture, horizontal shading has to be added, especially for openings, in order to protect the lower levels from the sun.

Space under roofs

Even though, insulation materials are available for contemporary architecture, space under roof can still be utilized as additional insulation. This improves indoor comfort with less material used. Therefore, decrease the cost of the building.

Elevated floor

The functional use of space under floor might be obsolete in contemporary buildings, but flooding is still a modern-day threat in central region and elevated floor can respond to this problem. Moreover, this design choice corresponds to method of insect protection in this project, since it provides an observable space to monitor insect attack. Even though, space under the first floor might not be suitable for a functional usage, it can provide space for mechanical services of the building, condensing unit of air conditioning system is a good example for this function.

Slope roofs

Lack of water proof roofing material was the main reason for high pitch roof in Thai vernacular architecture. With industrialized roofing material the angle of contemporary timber buildings can be much lowered.

Frame construction and prefabrication

Structural type and prefabrication go hand in hand for building designs. The choice of structural type has direct effect on the method of prefabrication in "Thai contemporary timber construction system". In this project, frame construction has been chosen as the most suitable structural type. This is due to, the current context of Thailand, where it is the most prevalent construction type for both vernacular architecture and contemporary architecture. For vernacular architecture, the large-dimension timber that will be use in "Thai contemporary timber construction system" can also be used in vernacular architecture. In the case of contemporary buildings in Thailand, it has established practice of frame construction, which this project can take advantage of. The process of familiarization of timber construction to Thai builders and designers can be facilitate by choosing the construction type that are more recognizable by these practitioners. In addition, choosing to emphasize on an aspect of design which are shared between vernacular and contemporary create a potential of convergence between the two type of architecture in the future. The new hybrid architecture, might have the capability of creating a design that truly belongs to the context of Thailand both in the subject of climate adaptations and life style of the users.

Since, frame construction has been chosen for this project, the degree of prefabrication has to be chosen accordingly. In the case Thai vernacular architecture, the prefabricated elements are limited to panels and roof frames. This came from the restriction of transportation in pre-industrialized age. Even though, in present days, the means for transport have been drastically improved, current transport in Thailand still has the same limitation. The street of Thailand can be very narrow. In smaller street, where residential buildings are often situated in, the size of the traffic are can be as small as six meters for two-way traffic. In a more extreme case, it can be reduced to four meters. This means that, prefabrication of large elements, which require an equally larger transport, is not an ideal solution for Thailand. Additionally, local Thai builders have limited capability of involving in the process of off-site construction. By limiting their interaction with the construction process, the familiarization of timber construction by "Thai contemporary timber construction system" will also be hindered.

Looking back at the prefabrication in vernacular architecture, its approach is still appropriate in the circumstance of this project[30]. Panels are the element that Thai vernacular architecture choose to prefabricate. These elements, in the studied European timber construction, are the most complicated and share the least similarity with the current practice in Thailand. They are also easily transportable in pre-assembled form. The roof structure, which has a lot of joints, is similar to wall panels. It can be easily transportable as finished form and become less time consuming to assemble. Additionally, roof structure has high degree of repetition in its design, which lend itself well with prefabrication. Lastly, climate protection during construction site is detrimental to the quality of finished buildings. The walls and roofs need to be assembled as fast as they can, so these elements can protect the primary structure from rain.

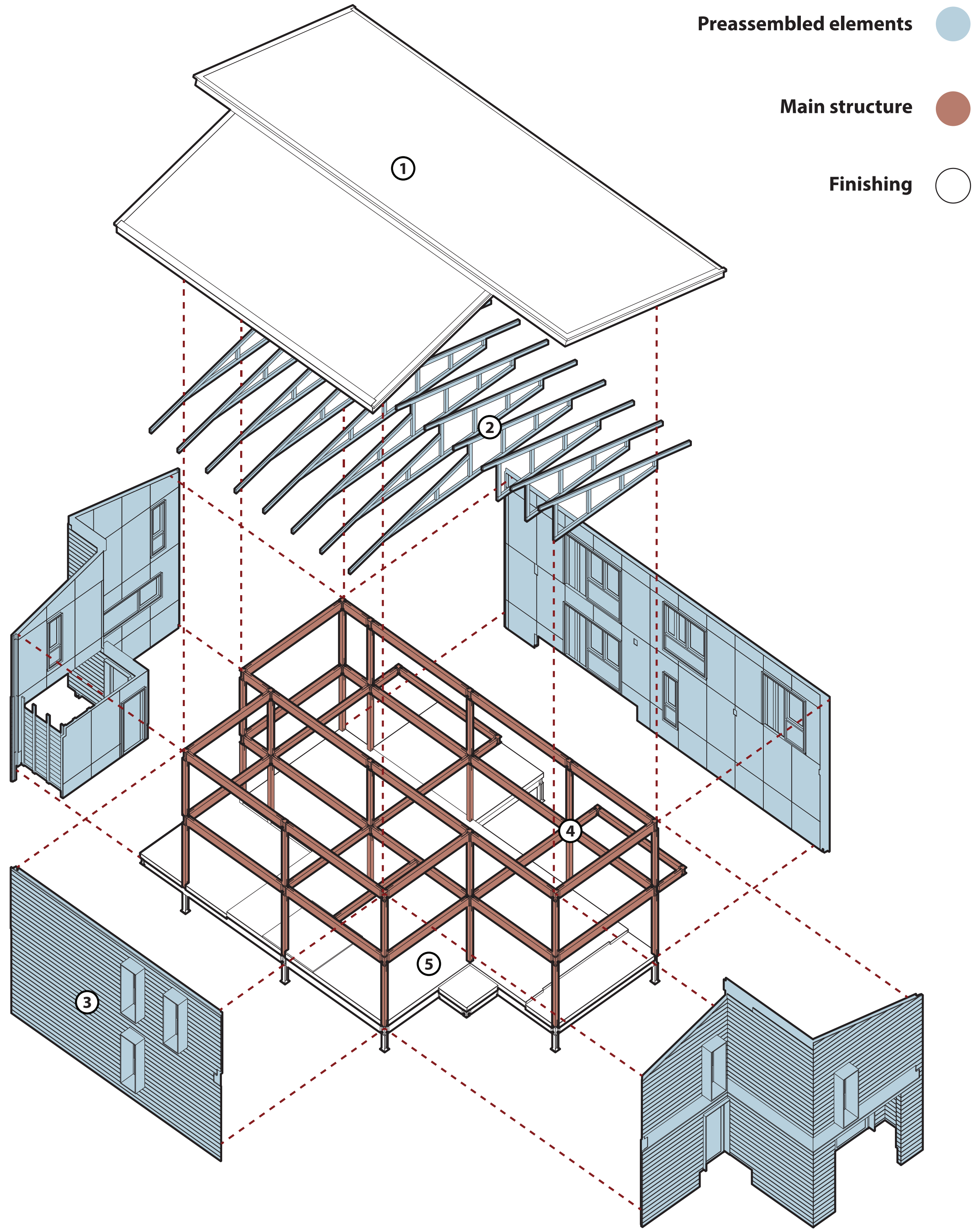
1. Roof
Roof element will be assembled on construction site for "Thai contemporary timber construction system". Due to its large size and limitation of tranportation in Thailand, pre-assembling this element will not be chosen for this system. The component that will use wood as the main material in its sub-structure and cheaper metal roof for finishing.

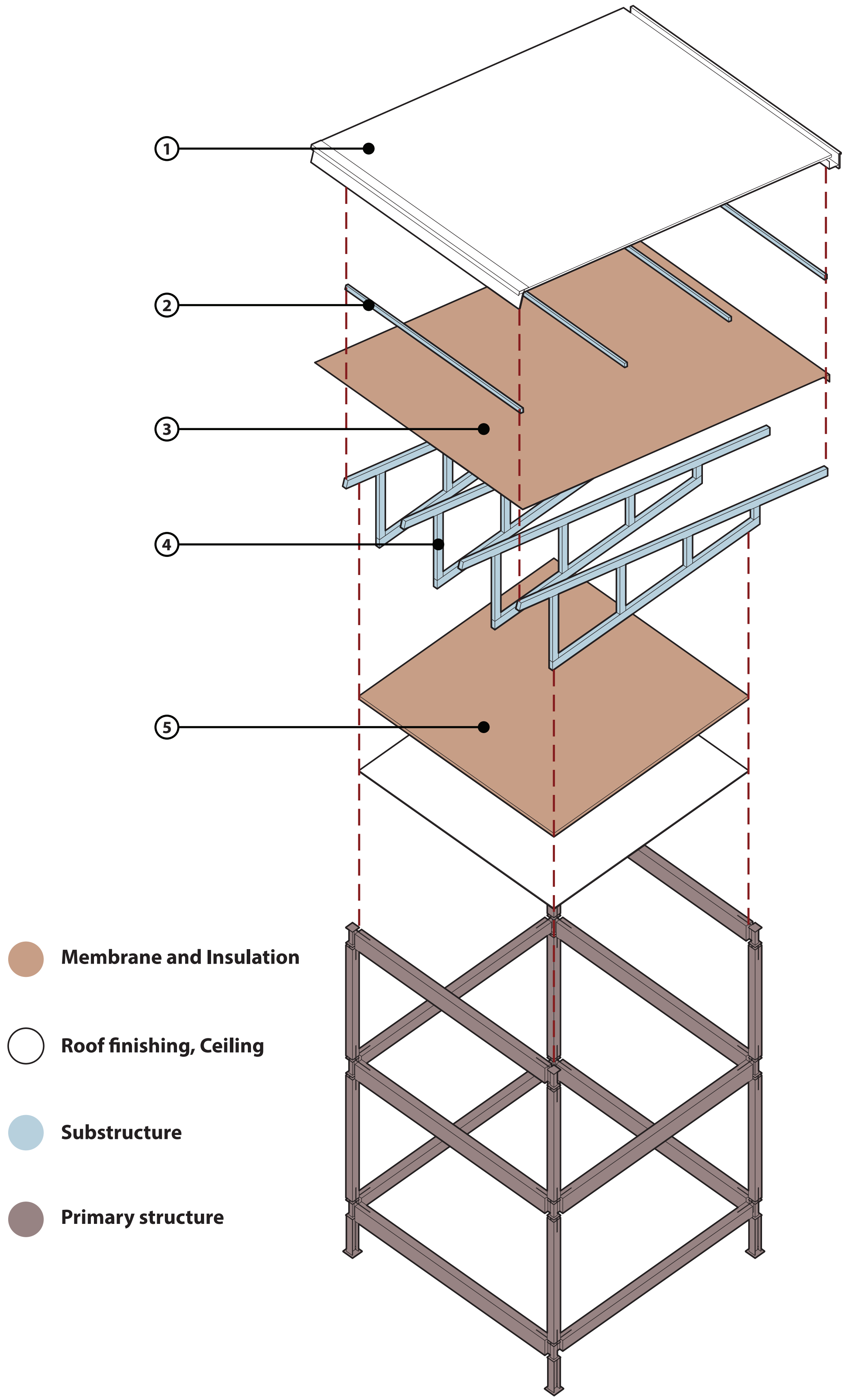
2. Roof truss
Roof truss is one of the components that is encouraged to be pre-assembled off-site. It has high degree of replicability, making it compatible with prefabrication concept. In normal size residential buildings, the size of these structural elements is not too large to be transported in its assembled form. These elements can use sawn wood as its materials or glued wood products for a larger roof truss.

3. Wall panel
Wall panels are the element which is most compatible with prefabrication concept. Walls have many layers and services in its components and should be built off-site. One continuous wall can also be assembled and transported separately, making wall panels consume less space. Boards, sawn wood studs and sawn wood planks are the wooden component in these elements.

4. Primary structure
This element will be built out of glued wood products, e.g. Glulam or Laminated veneer lumber. This is a strictly on-site construction, since its pre-assembled form takes too much space to be transport in Thailand. They will be connected to each other with steel joints.

5. Floor finishing
Floor finishing will be an on-site construction. This is another element that is difficult to be built off-site, due to its size and unpredictable form. It also does not offer any protection to rain in most cases, making it less important to be prefabricated. Sawn wood plank and studs will use wood as material in this element.





Building envelopment

European timber construction is the source of knowledge for the concept of layering in "Thai contemporary timber construction system". However, directly using the details found in European timber construction for this system will not result in a suitable building in Thai context. Further adaptation, simplification and addition of elements need to be applied to the studied details. Some of additional knowledge of building envelopment has to be gathered from other sources. Tropical savanna climate of Thailand has a hot and humid characteristic, which is drastically different from climate conditions in Europe.

Another aspect that needs to be considered is the substitution material. The main material that has been decided for "Thai contemporary timber construction system" is currently an imported one. In the case that these non-local sources are not available to Thailand in the future, possible substitute material has to be specified. This decision will allow the system to function without the existence of imported products.

In order to summarized the knowledge and the result of its implication, the detail of enveloping element for "Thai contemporary timber construction system" will be explained by each enveloping element in the following sections. The building elements that are exposed to the environment and need to perform as climate barrier are roof, walls and floor element of the first floor[17].

Roofing elements

Roofing elements in this project will be built with four group of components; finishing, sub-structure, membrane and insulation. In this analysis, the order of components will be established along with its materials and the logic behind its choice.

1. Finishing - Metal sheet will be used as the material for this element, since it is the most common, low cost and easy to assembled.

2. Purlin – Purlin is used to support roof finishing and hold the vapor barrier membrane to the roof truss or rafter. European pine sawn timber is the primary choice of material. In the case that imported wood is not available, local wood or steel can be the possible substitution.

3. Vapor barrier membrane – This element is used to protect roof structure from moisture in the case of leakage through roofing materials, which can happen from construction errors or material damage. This element will be attached in a way that allowed the water to flow along the slope, down to the gutter of the building. This element will also perform as a vapor barrier for the house. Hot humid climate of Thailand will create the condensation of water at the exterior side of the element. Therefore, it has to be placed on the exterior side not the interior[33].

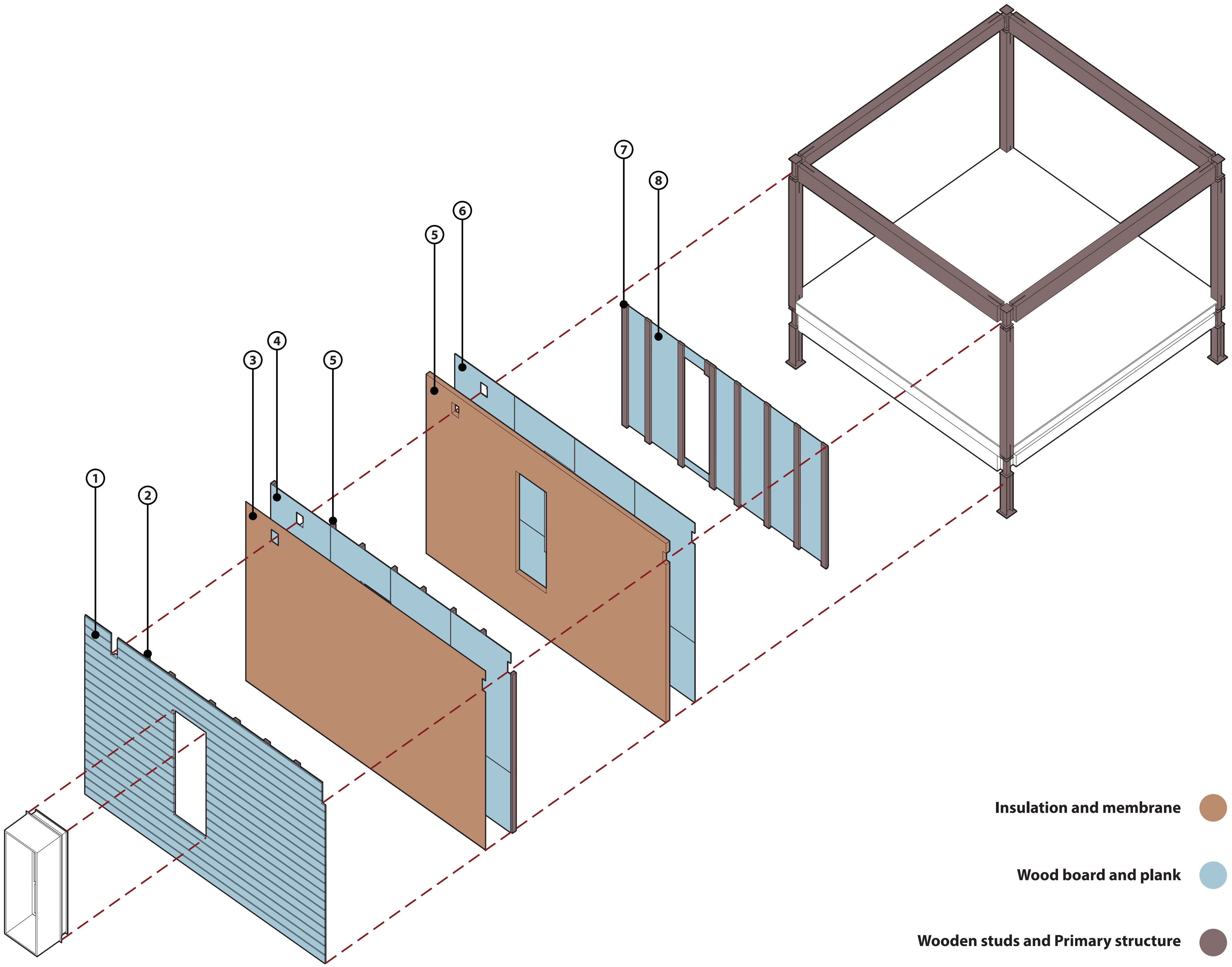
4. Roof truss or rafter - Is the primary load bearing element of the roof structure. Roof truss will be use in the case of longer column span. This is done to reduce the thickness of extended eaves. Timber rafter can be use in shorter span. When an extra ceiling space is needed in an interior space, rafter can also be employed to create a non-obstructed ceiling room. The logic for material choice is the same as purlin.

5. Insulation – Glass wool is the material of choice for this element due to its utilization of recycled material. In normal circumstance, insulation will be laid on top of the ceiling. This is done in order to effectively make use of the space under the roof as additional insulation element. This insulation element can be attached to the underside of rafters if the building needs extra ceiling room for indoor space.

17. KOLB, J. (2008). Systems in Timber Engineering
33. LSTIBUREK, J. (2002). Moisture Control for Buildings

Wall elements

Wall enveloping elements for buildings in Thailand are currently too simple to perform its environmental protection for "Thai contemporary timber construction system". It has to be drastically changed to improve its climate protection to the buildings. In order to facilitate the explanation of this analysis, wall elements will be divided in to three groups, exterior layers, core layers and interior layers. The followings are the detail of the layers and materials choice[17].



Exterior layers

1. Sawn wood plank - The outermost layer of wall elements, the choice of material is based on the intention to display the wooden texture in its tectonic form. The first choice of the material is European pine wood followed by local Thai wood, and in the most budget option, wood substitute products (fiber cement board).

2. Exterior plank studs - This is the structural element for the support of sawn wood plank. The orientation of these studs will be all vertical. This allowed the air to circulate behind sawn wood planks and enabled them to dry more effectively. It will be made of European pine wood, local Thai wood or steel, the priority for the material is in this respective order.

3. Vapour barrier membrane – Following the same logic as vapour barrier membrane applied on the roof, this element act as vapor barrier and has to be place on the exterior side of the wall in order to prevent water condensation inside the wall structure.

Core layers

4. Exterior core panel - A board element that will be used to hold external plank stud to the building. Since this is a load bearing element, the strength of the material factors in with the material choice. European plywood has products with enough thickness to perform this function. The local plywood however, is not suitable for loadbearing and need to be replace with local cement fiber board for the secondary option.

5. Insulation and core stud - This layer is consisted of wooden studs and glass wool infill. The thickness of the insulation layer will be 75 millimeters. This is the most optimal thickness of insulation for maintaining indoor comfort temperature in Thailand. Material for the wooden studs in core layer is the same as the one in exterior layer[34].

6. Interior core panel - Interior core panel is the layer that will be connected with the primary structure of the house. Core studs will be connected to this layer as well as interior wall studs. This element, along with core studs, also helps stiffen the primary structure of the house, which is mandatory for frame construction. The material choice is exactly the same as exterior core panel.

Interior layers

7. Interior studs – They are used to hold finishing panel to interior core panel. Additionally, all of the building service wires and pipes will be secured between these studs. These services include electrical, plumbing and air-conditioning systems.

8. Finishing panel - The interior finishing layer of the wall elements. European finishing grade plywood is the first material choice due to its sustainable source and ease of assembling. Alternative local material will be painted gypsum board for a budget option.

17. KOLB, J. (2008). Systems in Timber Engineering
34. PICHETSILPA, K. (2002). A Guideline for building wall system to improve thermal performance.

Floor elements

Floor elements is also another element that is underdeveloped in term of its climate protection. Like all the other elements, adjustment need to be made to this element in order to increase its protective performance. The important different for floor element is that it needs to employ a solution to a problem of Formosan subterranean termite, which is a wide spread species in Southeast Asia. This is not a knowledge that can be found in European timber construction. Therefore, this solution has to be introduced to "Thai contemporary timber construction system" in other way[17].

1. Steel plate - Steel plate is the element that is chosen to address the problem of termite. The steel plate can be attached to the underside of ground floor beams and sealed between its seams, in order to limit the access to the building by termites.

2. Vapour barrier membrane - This layer performs as the vapor barrier for the house and follow the same logic as roof and wall elements.

3. Insulation - Glass wool is the material for this layer, similar to all other insulation layers. It is attached between floor beam spacings.

4. Floor studs - The main secondary structure used to support the floor finishing element. European pine sawn wood is a preferred material with local wood and steel as secondary choices.

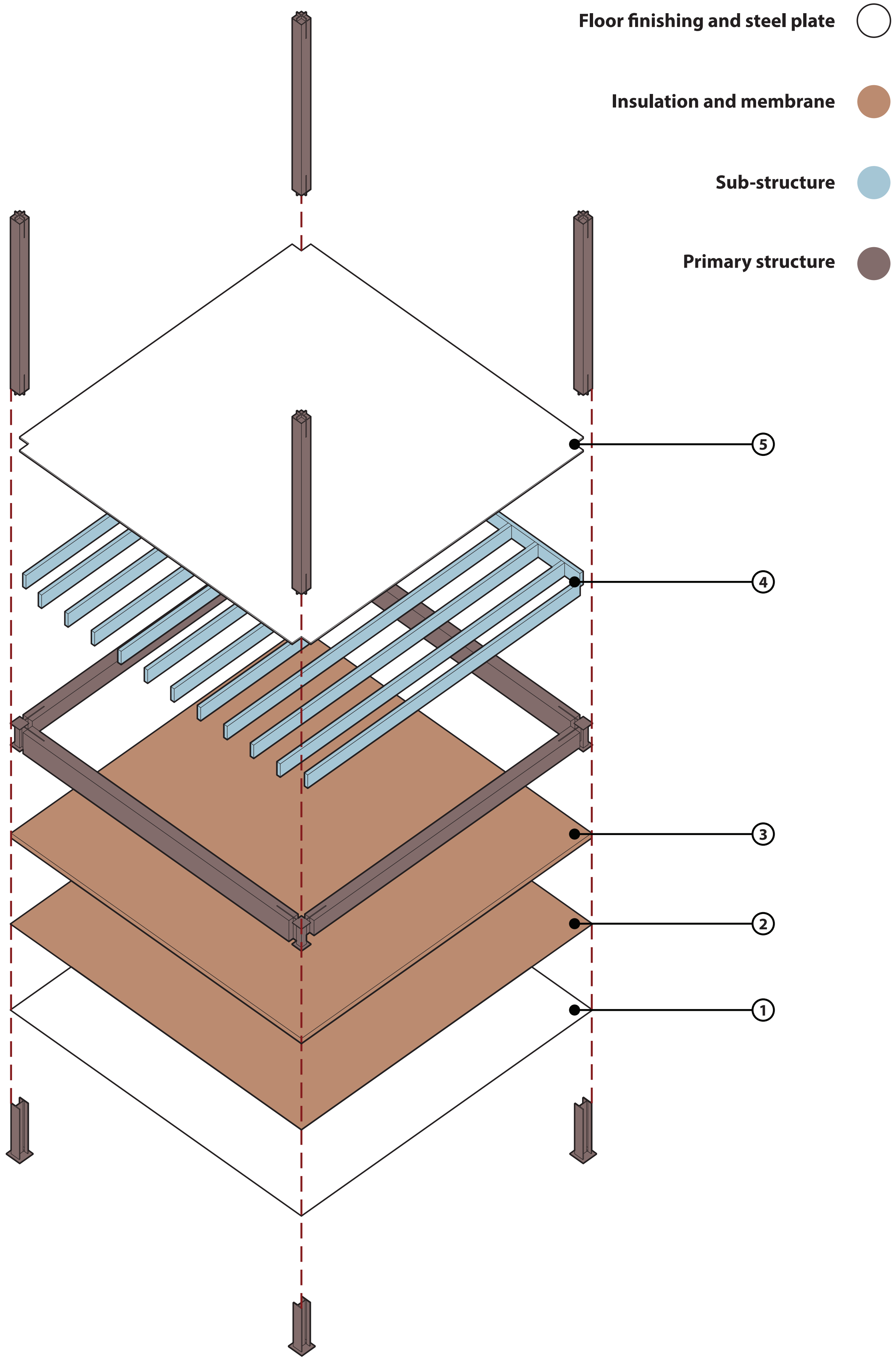
5. Floor finish – Similar to exterior wall finish, sawn pine wood is the material of choice in order to display the texture and aesthetic of wood. Local wood or fiber cement can also be a possible alternative material.

Substitute materials

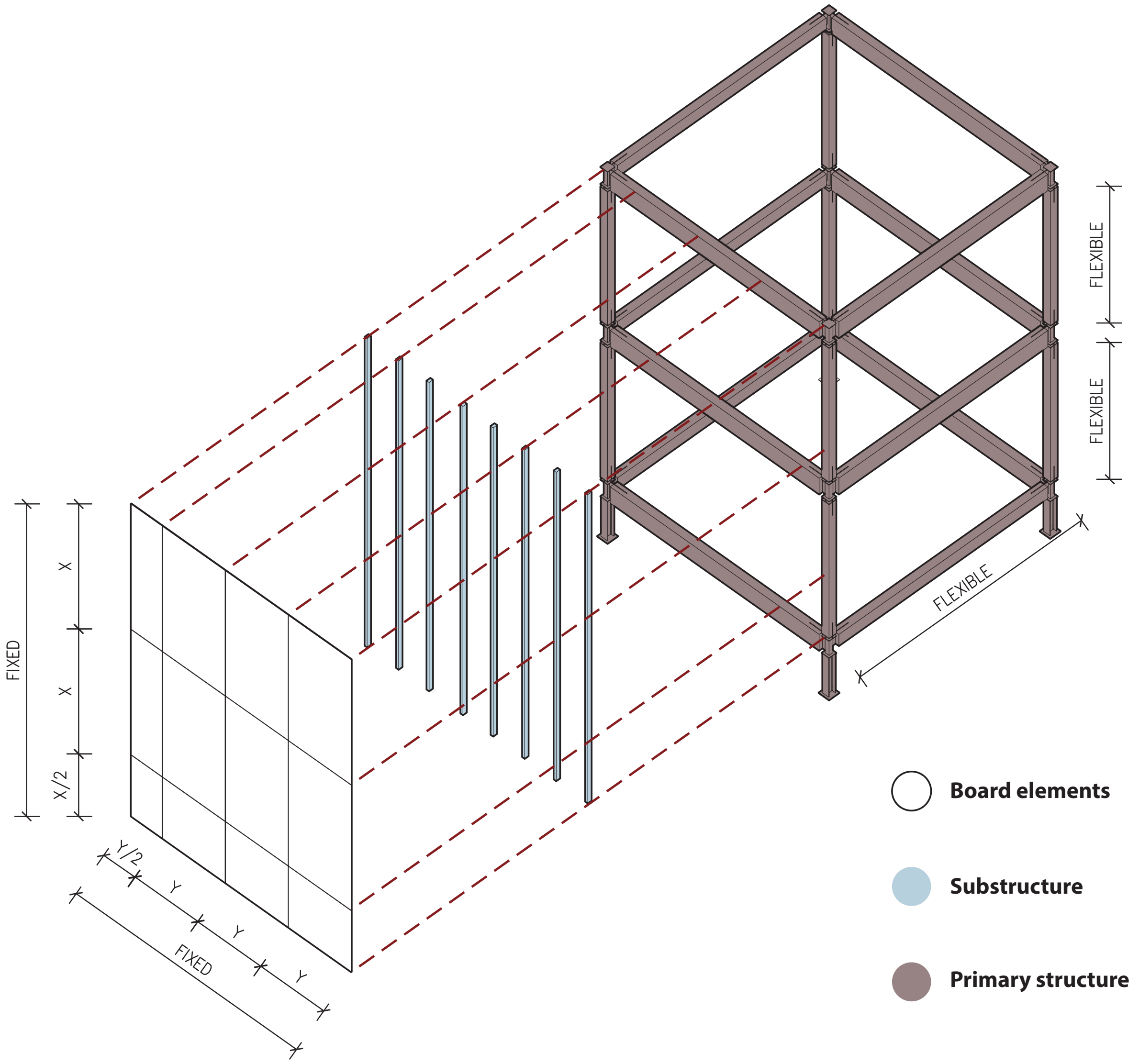
fig 73. Subtitute Material: Steel

fig 74. Subtitute Material: Local Timber

fig 73. Subtitute Material: Steel - source: Viriyaroj B.
fig 74. Subtitute Material: Local Timber - source: Viriyaroj B.
17. KOLB, J. (2008). Systems in Timber Engineering



Standardization and modularity

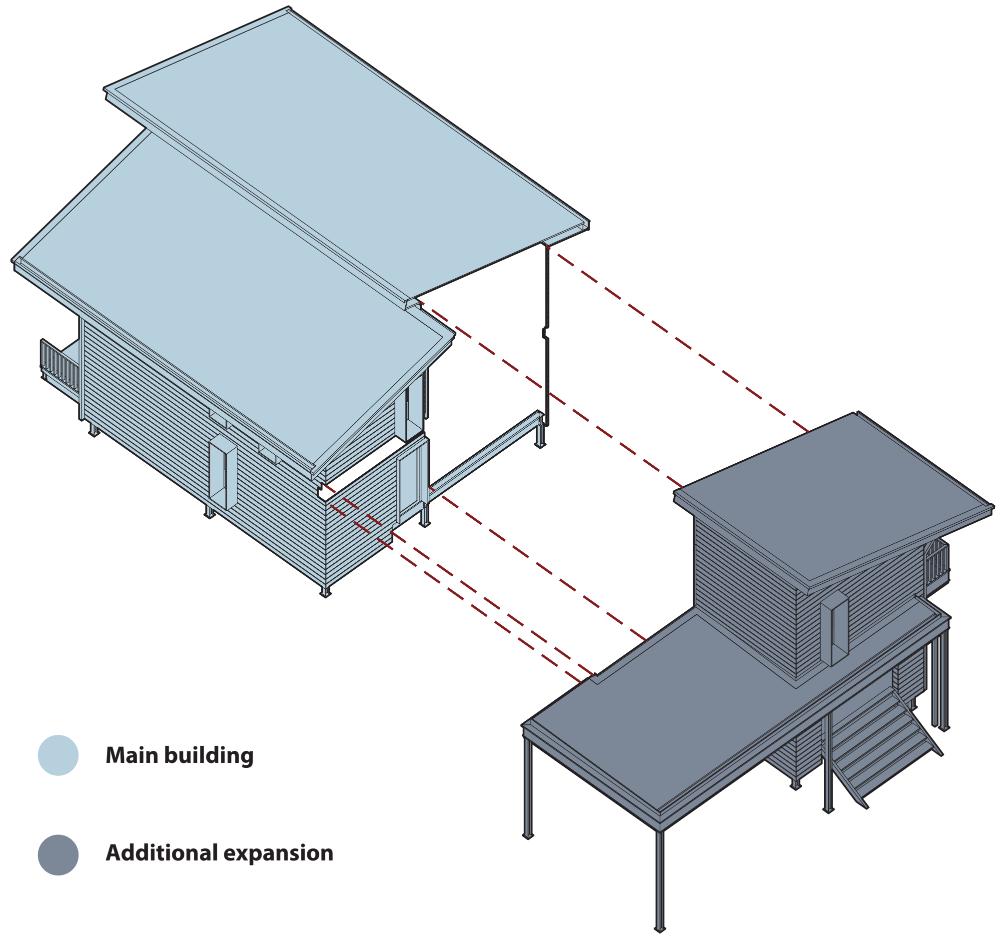


Efficiency is one of the most important subjects in this thesis, since it affects two fundamental challenges "Thai contemporary timber construction system" needs to face. Competition with conventional construction is the largest obstacle for the development of timber construction in Thailand and construction cost is the decisive element in this competition. Even though, in the current situation, it is not possible to build with timber and make them cheaper than concrete houses, wooden house has other advantage that can make it more appealing than concrete construction. These advantages however, will still need to be accompanied with a reasonable price, and efficient use of material can reduce the price of timber construction. Similar to construction cost, using material affectively also benefit environmental impact of the building. With less material usage to assemble a building, its carbon footprint will also be lowered.

Efficient use of material in this project will be execute through the use of standardization and modularity in design. The most basic decision for the adoption of standardization to the project is to avoid using custom dimension components. All of the components in the prototype building designs should be utilizing the standard sized products. This design decision is particularly important to timber construction, where each building components has their inherent dimension from manufacturing process. In the case of linear timber product, this inherent dimension applies to width and depth of the member, while the length can still be flexible. For board products however, all three dimensions are fixed in the standard off-the-shelf product. By carefully integrate these dimensions to the "Thai contemporary timber construction system", it can avoid unnecessary waste of material. Another beneficial aspect of dictating dimensions in construction is that, it helps reducing learning curve of the new craft to the unfamiliar construction workers and designers. Establishing a basic rule of standardization to the project can reduce unnecessary decision-making process to the designers and construction workers, which will facilitate the working process and make timber construction easier to execute for them.

Standardization can also be used in conjunction with modularity to further improve the efficiency of material for the design of each house. The dimension of each column span should be dictated by the modularity of a building element with the strictest dimension. In the case of "Thai contemporary timber construction system", board element has the most fixed dimension of all the building component. For European timber products, board elements still come in various sizes[35]. Therefore, this modularity has to come from other criteria. Since, the source of main material in this project need to be imported, the system design should be compatible with local material in the case that substitute material is needed. In Thailand the dimension of board element has less variation than European wood products. The most common dimension for these local materials is 2,40x1,20 meter, and "Thai contemporary timber construction system" will be design from this dimension. In addition, this modular units have to take in to account the errors on the process of assembling and the space needed to add sealant between each board. This mean that, the dimension of each column span will be the sum of total dimension of all board elements plus small gap for errors and sealants. For example, 4,80 meter is the dimension of 4 boards combine. Five extra centimeter will then be added to this dimension, resulting in the column span of 4,85 meter. This addition of extra space only applies to horizontal dimension, since space under the first floor can be used to accomodate the extra space. In the case of conflict between this modular unit and other design factors, designers can choose to refrain from its application if needed.

There is another use of modularity which can be adopted from Thai vernacular architecture. Thai vernacular architecture has used the concept of modularity to solve several challenges it has encountered. Some of these challenges are still relevant in the current context of Thailand. The challenge of relocation has disappeared in modern lifestyle, with the development of land ownership in Thailand. Nevertheless, change in the number of family member still happen throughout a life cycle of a house. Modularity can create a more effective adjustments to accommodate the change in family units. Combining modularity with design for disassembly can greatly enhance this degree of adaptability to the houses, in respond to family dynamic. Modularity and design for disassembly enable the buildings to be flexibly attached and detached, which allow the buildings to change without rebuilding or with shorter renovation process[30].



35. Woodproducts.fi. (2019). [online] Available at: https://www.woodproducts.fi/sites/default/files/a_buyers_guide_to_wood_products_2018_0.pdf [Accessed 27 Aug. 2019].

Wood to steel connection

Steel has good synergy with timber as construction materials, and it has already been commonly utilized in European timber construction. They are used for joining multiple wooden elements together, capitalizing on their strength and malleability. Wood is still the main material in this scenario, which make the timber construction retain its lightweight and positive environmental impacts. Aside from these general benefits of using wood to steel connection, there is anotherl advantage that can be gained by using it in "Thai contemporary timber construction system". These additional advantages can enhance the other design principles that has been previously established.

Reduce the learning curve for Thai builders

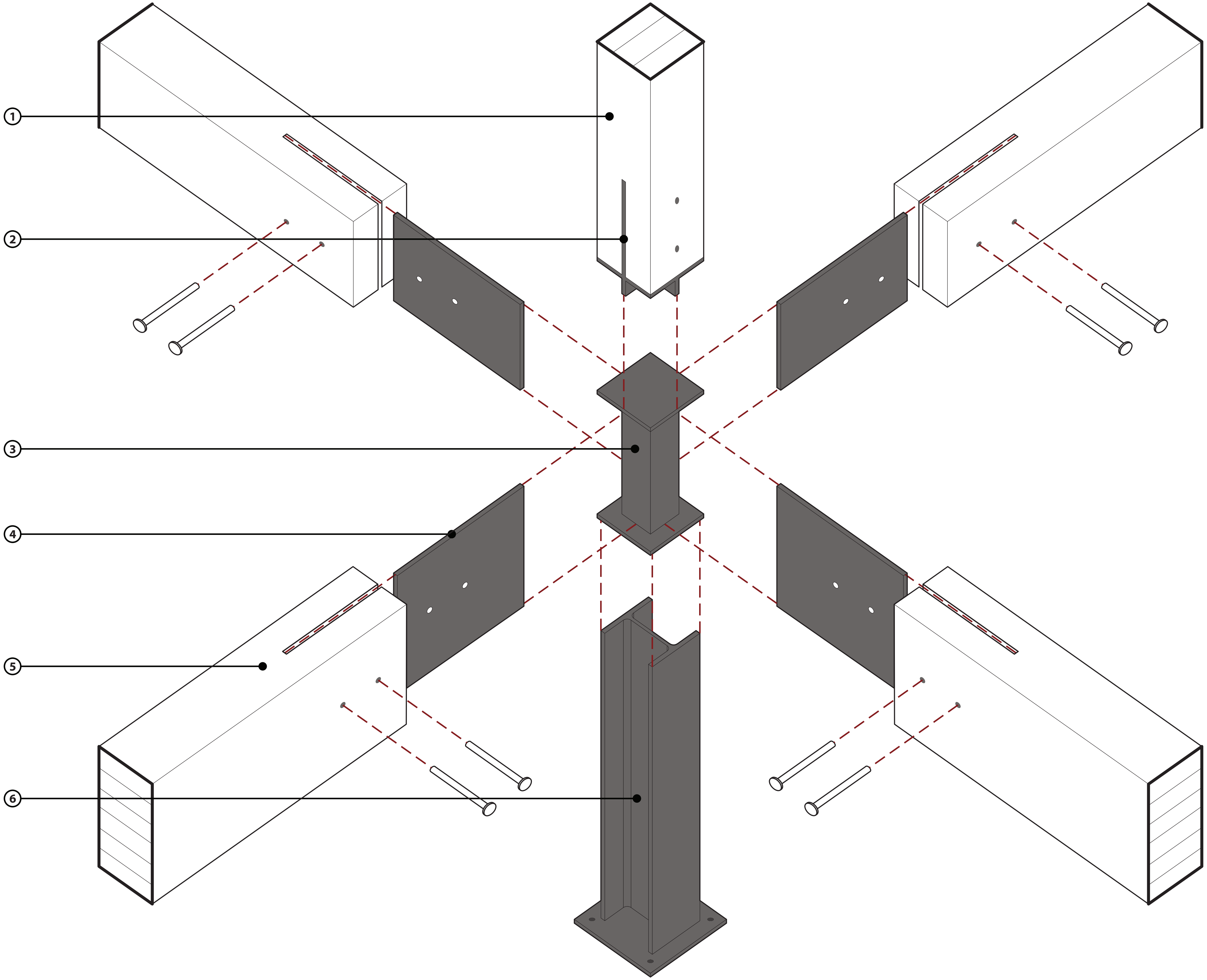
Errors in the assembling process of primary structure has the most potential for catastrophic failures in all of building components. In order to avoid these errors, experience builders are needed to execute these assembling processes. Unfortunately, lack of experienced timber construction builders is one of the major obstacles in building wooden house in Thailand, and it is the challenge that "Thai contemporary timber construction system" is trying to address. As it has been previously stated, steel construction is a well-developed practice in the context of Thailand, especially with welding. These welders will have less risk to create errors to steel joints than wooden one, since it is the craft that they are more familiar with. By allowing these steel construction workers to engage in timber construction, it provides more experienced builders into the process of timber construction. These builders can still engage and learn the practice of timber construction in other part of the building where errors are more forgiving, such as sub-structure or finishing.

fig 75. Steel Construction in Thailand

fig 75. Steel Construction in Thailand - source: Viriyaroj B.

fig 76. Wood to Steel Connection

fig 76. Wood to Steel Connection - source: http://konstruksi.clash-royale.info/structural-steel-knife-connection.html#



General wood to steel joint detail

1. Glulam timber column
Wood is the major material in this element, while steel will be use only at the end of column and serve as connection to “Core steel joint”. This wooden column and its steel joint should be measured and fitted off-site, in order to ease the process of on-site assembling. It can then be transport to the site, the steel column joint will be welded to “Core steel joint” before the timber part can be bolted and fixed to the main structure. This is done to prevent damage to wooden elements during the welding process. In the case of disassemble, the bolts can be taken out and wooden part can be removed from the structure with ease.

2. Steel column joint
Steel joint for columns are embedded in to Glulam column with the use of bolts. It will be connected to the “Core steel joint” with either welding or bolts. Welding is the more preferable choice in the context of Thailand, since it is a more widespread practice. Steel column joint has a cross shaped section to stabilize its connection with “Core steel joint”.

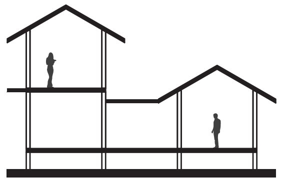
3. Core steel joint
“Core steel joint” is the connection junction for primary structural elements. It will be built from a square steel tube in the center and has steel plate caps on both ends. When assembled, the tube will be connected with beams, while the caps will be joined with columns. The size of “Core steel joint” depends on the size of its connected elements.

4. Steel beam joint
This element performs a similar role as “Steel column joint” but it will be connected to Glulam beam instead. It came in a form of simple steel plate, which will be inserted on-site and bolted vertically at the end of each beam.

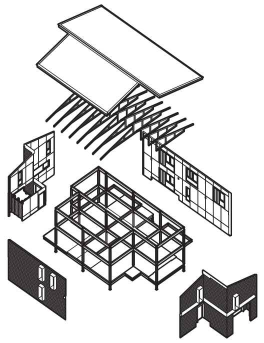
5. Glulam timber beam
This wooden element shares the same characteristic as Glulam timber column, but used as a beam. This element should also be joined with its steel joint after the the welding process.

6. Steel column
Steel column only exist below the first floor. This is the element that will be connected with the foundation and will exposed to the ground, which make wood not a suitable material for this element.

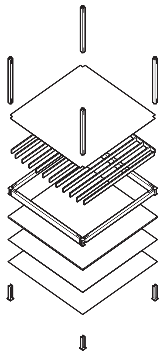
Key principles of system design



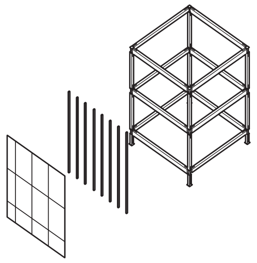
- Climate adaptation principles from Thai vernacular architecture are; horizontal shading and eaves, space under roofs, elevated floor.



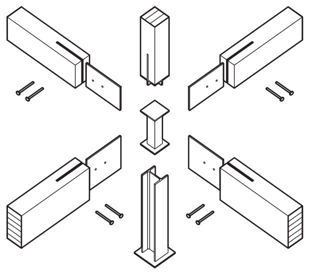
- Frame construction is chosen for the structural type of this project
- Prefabrication of panel elements and roof frame will be used along with on-site frame construction.



- The layering concept of European timber construction will be utilized in this project and will be accompanied with several adjustments, to make it fit with Thai climate.



- Off-the-shelf products will be the primary choice for building components in this project.
- The modularity based on the dimension of board element will be integrate to the building design.



- The connection of primary structure will use wood to steel connection.

fig 77. Bangkok Street - source: Viriyaroj B.

VII. Sites for Prototype Buildings

Bangkok urban zoning

After the construction system has been established, the next process for development of "Thai contemporary timber construction system", is choosing the sites for the three prototype houses. All three sites will be situated in Bangkok, the capitol of Thailand, where more than 10 percent of Thai population resides. This is also the city, which has the most developed urban zoning. This will be one of the important criteria for choosing sites. In the urban zoning of Bangkok, several rules dictate the type and size of buildings that can be built in each zone. Since not every rule is related to this project, the important one will be picked and use as criteria for building sites. There are 5 relevant rules "Thai contemporary timber construction system" needs to be taken in to consideration.

1. Building type – In this rule, urban zoning determine which type of building can be built in each zone. For residential buildings, the definition of building types can be found in Thai building regulations and they are defined as followings.

- "Residential buildings" means buildings with day-night occupation, both permanently and temporary
- "Row-rooms" means buildings which has at least two units that are built inter-connected to one another. Each room is divided by separate walls and mostly builds with Non-fire-resistant materials.
- "Row-blocks" means buildings which has at least two units that are built inter-connected to one another. Each room is divided by separate walls and mostly builds with Fire-resistant materials.
- "Row-houses" means Row-rooms or Row-blocks which are used for residential purposes. These buildings have open spaces in the front and back of the houses. The maximum number storeys for these buildings are three storeys.

fig 78. Row-rooms

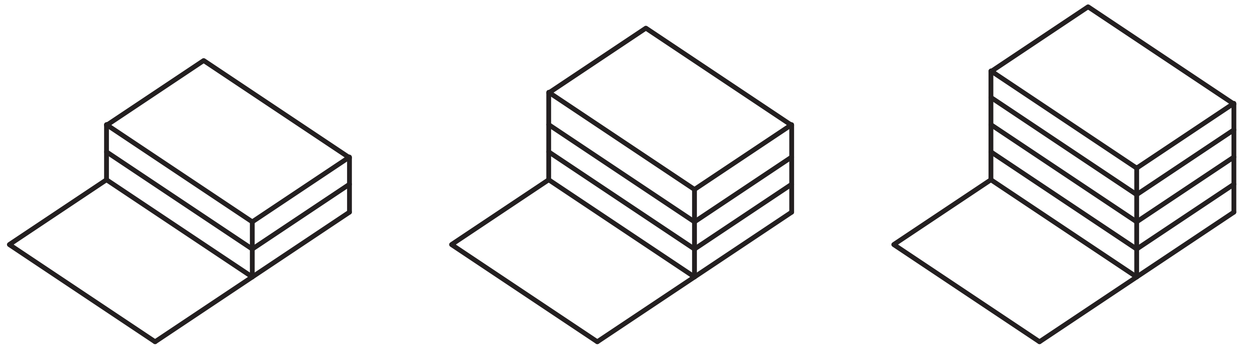
fig 79. Row-blocks

fig 80. Row-houses

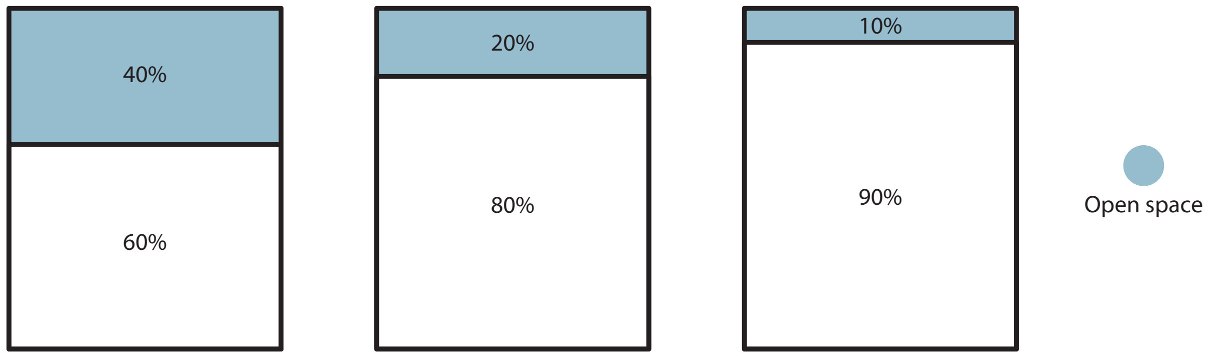
These are the definition of each type of residential buildings. There is no direct definition for detached houses, but it is a common form of building and can be understood without any additional description. According to the regulation, the house type for the Row-house in this project is classified as "Row-rooms", this is a straight forward translation from Thai language. Generally, Bangkok zoning allowed every urban zone to build some type of residential buildings. However, some of the zones has restriction towards certain types. Some zone does not allow apartment buildings to be built, while some zone only allowed the construction of detached house. The priority of these restriction is in the top down order. This means that, if a large-scale residential building is allowed in a zone, all of the smaller scale buildings will also be allowed as well. Nevertheless, efficient land use should also be a factor of concern for "Thai contemporary timber construction system". Therefore, the site of prototype housing will be chosen within the most suitable urban zone. For example, the zone that allowed the construction of "Row-rooms" will not be chosen for detached houses, since there is urban zone that only allowed the construction of detached houses and no other house type.

fig 78. Row-rooms - source : https://www.tripadvisor.ie/LocationPhotoDirectLink-g2237221-d12640001-i266355771-Rim_Nam_In_Buri-In_Buri_Sing_Buri_Province.html
fig 79. Row-blocks - source: https://th.wikipedia.org/wiki/ไฟล์:ตึกแถวแพร่งภูธร188.jpg
fig 80. Row-houses - source : https://zmyhome.com/sell/house/ทาวน์โฮม-Pleno-ปิ่นเกล้า-_-วงแหวน/30819

2. Floor area ratio (FAR) – This rule dictates the functional area of the house in comparison to the size of the land area. For the zone with low floor area ratio, only a house with smaller functional area can be built. In effect, this rule limits the number of storeys for each house. An urban zone with floor area ratio of 1 means that, the house with 50% site coverage can only have two floors. The house type that will be restricted by this rule is the row-house or "Row-room", in Thai regulation. The row house for the family units in this project will have approximately 70% site coverage. This means that, this house type has to be built in the urban zone with at least 1.4:1 floor area ratio.



3. Open space area – Open space area restrict the coverage area of buildings in each site. The element that is counted as coverage area are the one with any structure higher than 1,20 meters. This rule also mostly affects row houses. Any zone that require more open space area than 30 cannot be chosen as a site for row house, since it has around 70% site coverage.

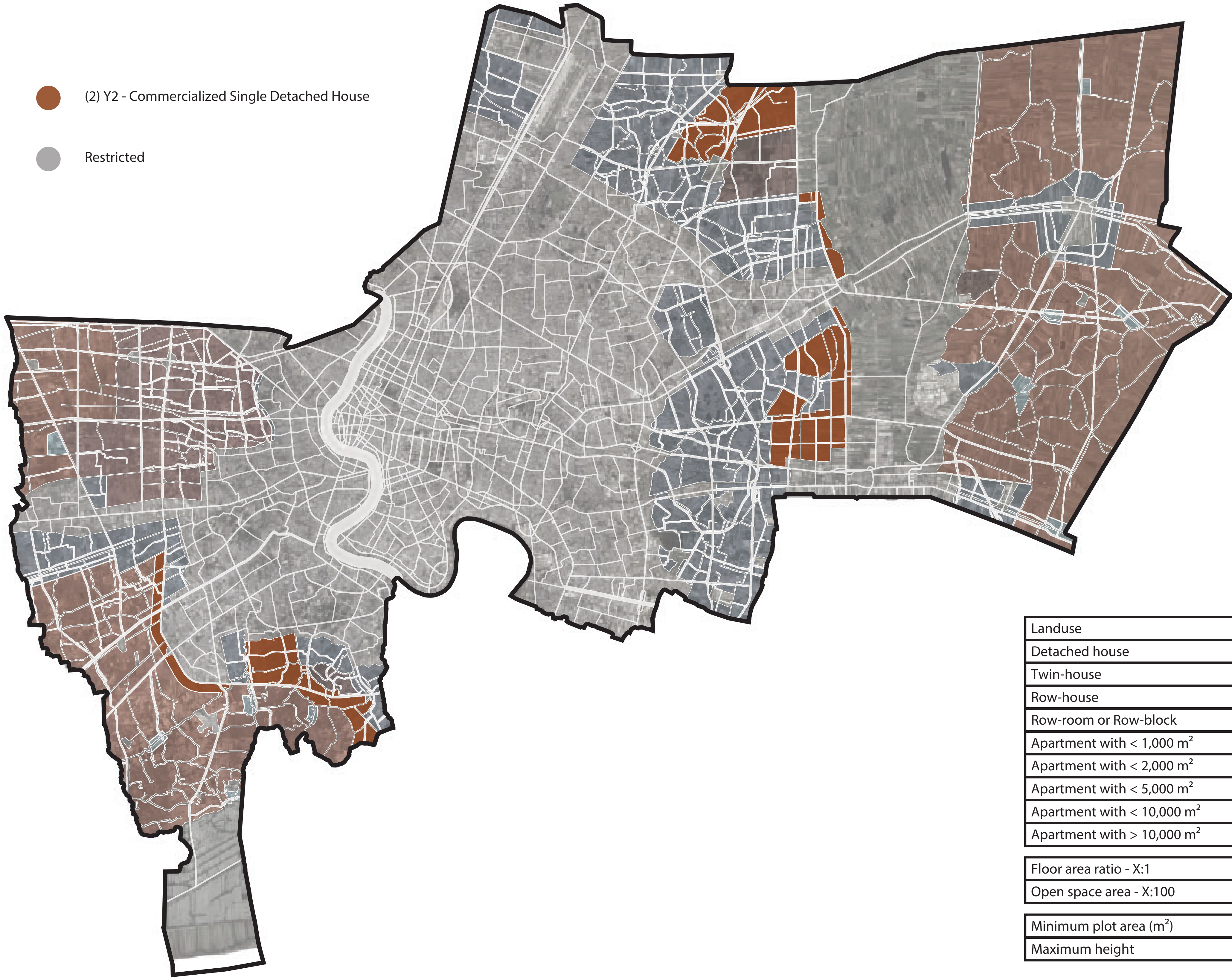


4. Minimum plot area – This rule mostly effects commercial houses. The size of the land plot is one of the most important factors for commercial houses. Land efficiency decrease the cost of the project and commercial houses tend to have the site that fit the house. For commercial detached house in this project, the land area is usually smaller than 300 square meters. As for the row house, they will be built in the site with less than 150 square meters land area. Therefore, any urban zone that has minimum plot area higher than these number cannot be chosen for the site of those buildings.

5. Maximum height – Some urban zoning has height restriction. However, there are no urban zone that has lower than 12 meters height restriction in Bangkok. Thus, this rule does not have any effect to this project, since wooden house has the maximum storeys of two, around 7-9 meters.

Bangkok urban zoning are categorized by codes of one Thai alphabet and one digit of number. In order to make the code understandable in English, I have decided to replace the Thai alphabet with English alphabet that has similar sound. There are five zones that has been chosen for the sites of this project and their codes are Y1, Y2, Y3, G4 and G5. All the other zones allowed the construction of building types which are larger than the scale of houses in this thesis, thus will not be taken to consideration.

Zoning for commercial detached house

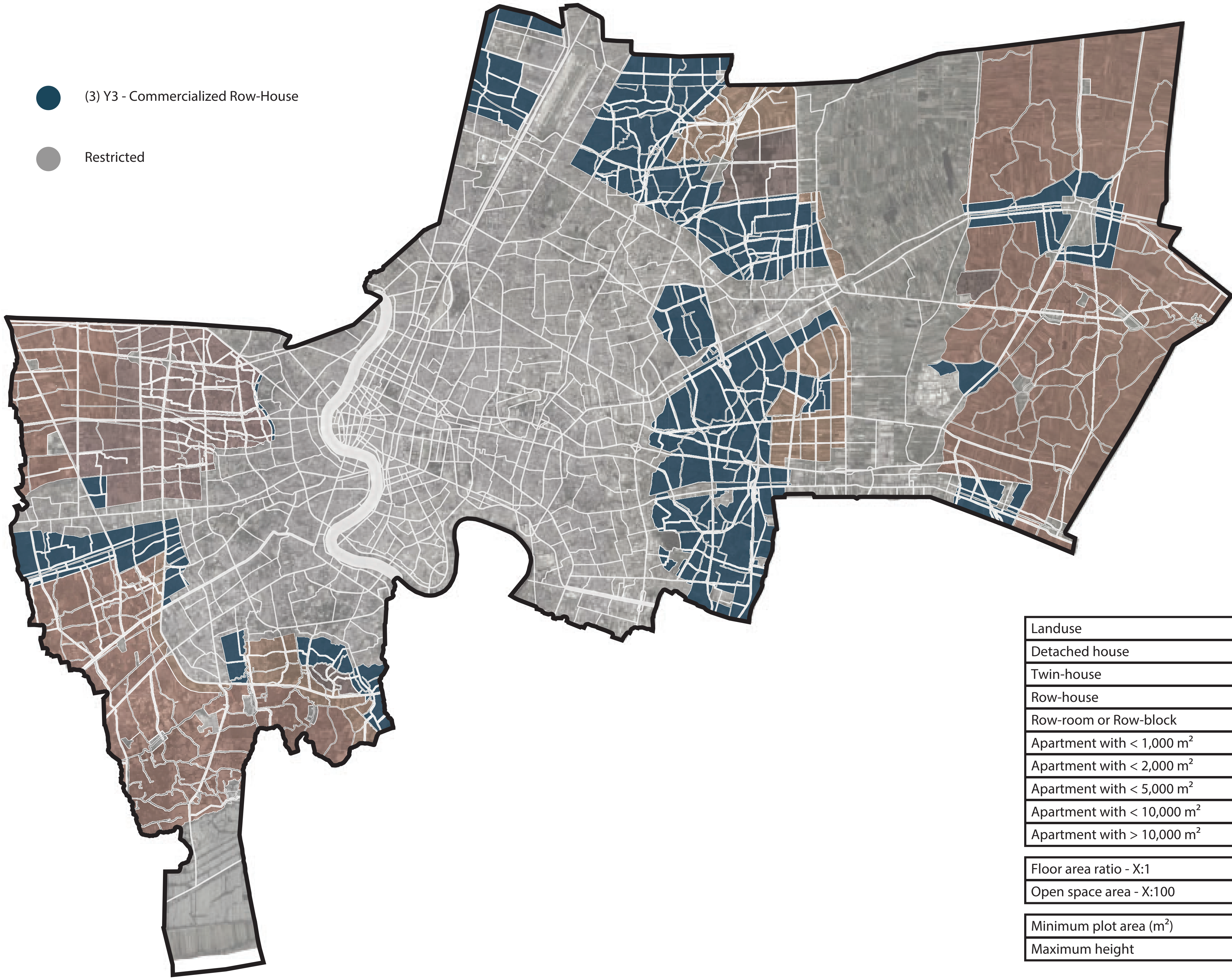


Landuse	Y1	Y2	Y3	G2	G4
Detached house					
Twin-house					
Row-house					
Row-room or Row-block					
Apartment with < 1,000 m²					
Apartment with < 2,000 m²					
Apartment with < 5,000 m²					
Apartment with < 10,000 m²					
Apartment with > 10,000 m²					

Floor area ratio - X:1	1	1.5	2.5	1	1
Open space area - X:100	40	20	12.5	40	40

Minimum plot area (m²)	400	200		400	400
Maximum height	12	12		12	12

Zoning for commercial row house



Landuse	Y1	Y2	Y3	G2	G4
Detached house					
Twin-house					
Row-house					
Row-room or Row-block					
Apartment with < 1,000 m²					
Apartment with < 2,000 m²					
Apartment with < 5,000 m²					
Apartment with < 10,000 m²					
Apartment with > 10,000 m²					

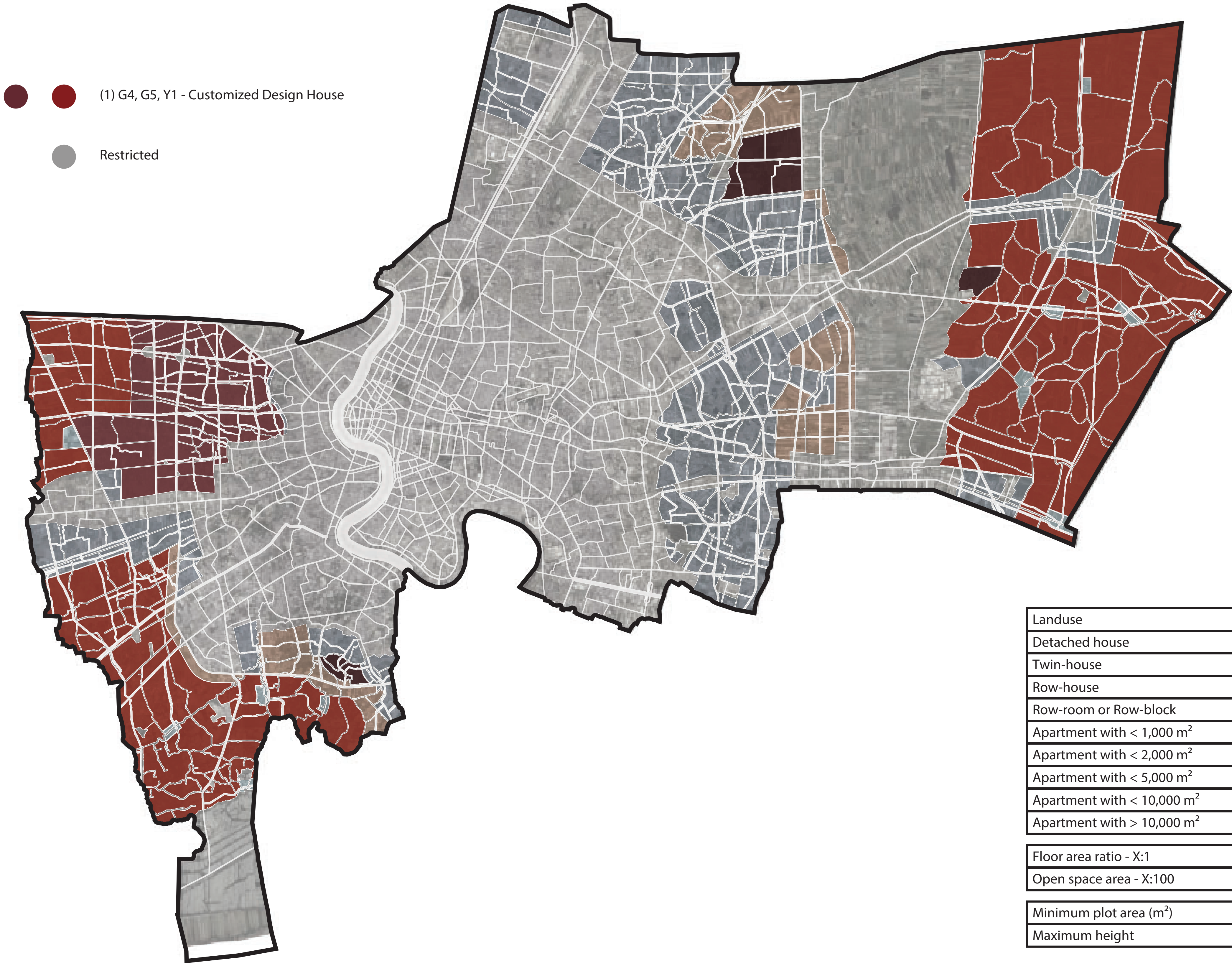
Floor area ratio - X:1	1	1.5	2.5	1	1
Open space area - X:100	40	20	12.5	40	40

Minimum plot area (m^2)	400	200		400	400
Maximum height	12	12		12	12

Zoning for custom design house

(1) G4, G5, Y1 - Customized Design House

Restricted

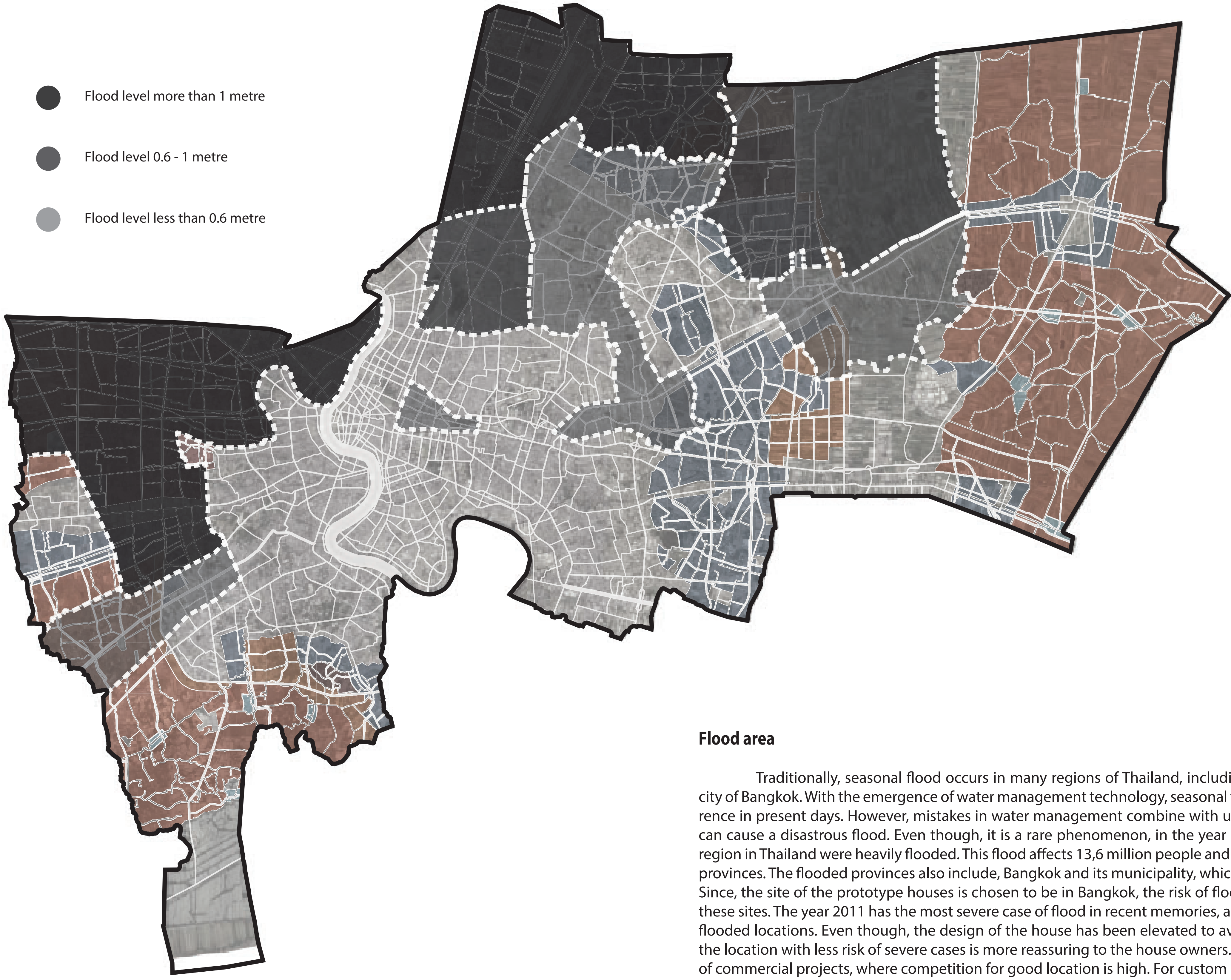


Landuse	Y1	Y2	Y3	G2	G4
Detached house					
Twin-house					
Row-house					
Row-room or Row-block					
Apartment with < 1,000 m^2					
Apartment with < 2,000 m^2					
Apartment with < 5,000 m^2					
Apartment with < 10,000 m^2					
Apartment with > 10,000 m^2					

Floor area ratio - X:1	1	1.5	2.5	1	1
Open space area - X:100	40	20	12.5	40	40

Minimum plot area (m^2)	400	200		400	400
Maximum height	12	12		12	12

Bangkok 2011 flood map



Flood area

Traditionally, seasonal flood occurs in many regions of Thailand, including the central region and Thai capital city of Bangkok. With the emergence of water management technology, seasonal flood in Bangkok is not a regular occurrence in present days. However, mistakes in water management combine with unusually high amount of precipitation can cause a disastrous flood. Even though, it is a rare phenomenon, in the year 2011 North, Northeastern and Central region in Thailand were heavily flooded. This flood affects 13,6 million people and spread out through 65 of Thailand's 76 provinces. The flooded provinces also include, Bangkok and its municipality, which suffers for more than one full month. Since, the site of the prototype houses is chosen to be in Bangkok, the risk of flood should be considered as criteria for these sites. The year 2011 has the most severe case of flood in recent memories, and can be considered as a base line for flooded locations. Even though, the design of the house has been elevated to avoid damages from flooding, choosing the location with less risk of severe cases is more reassuring to the house owners. This is particularly relevant in the case of commercial projects, where competition for good location is high. For custom design house, this project can take the liberty of choosing flooded locations, since the owners of the flooded land plot should have the opportunity to build a house on their land. This can also be an opportunity for "Thai contemporary timber construction system" to test its flood handling capability.

fig 81. adapted from - https://www.thaitravelblogs.com/2011/10/map-of-flood-risk-areas-in-bangkok/

Bangkok train routes map

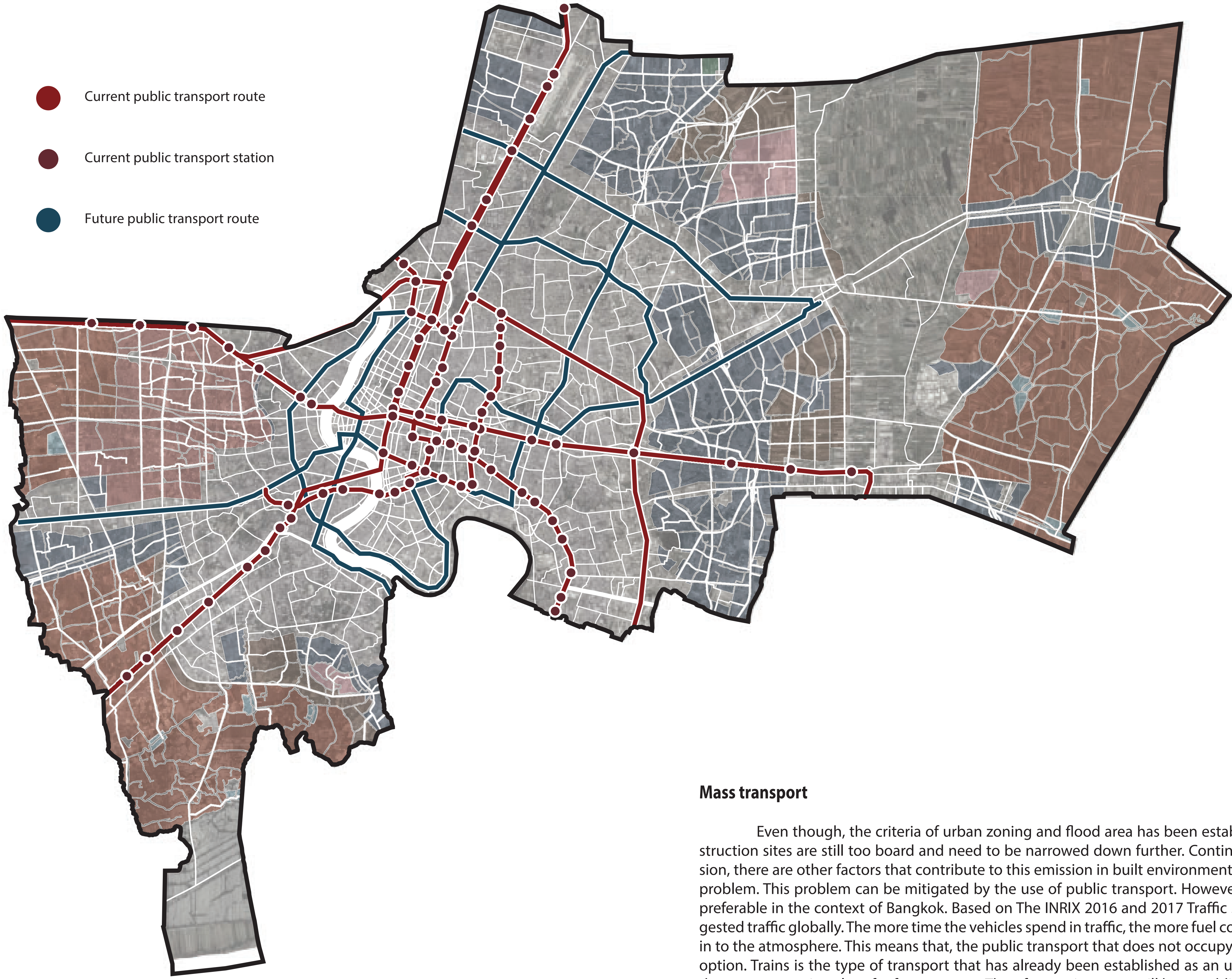


fig 82. adapted from - http://www.gregtodiffer.com/the-future-of-bangkoks-mass-transit/

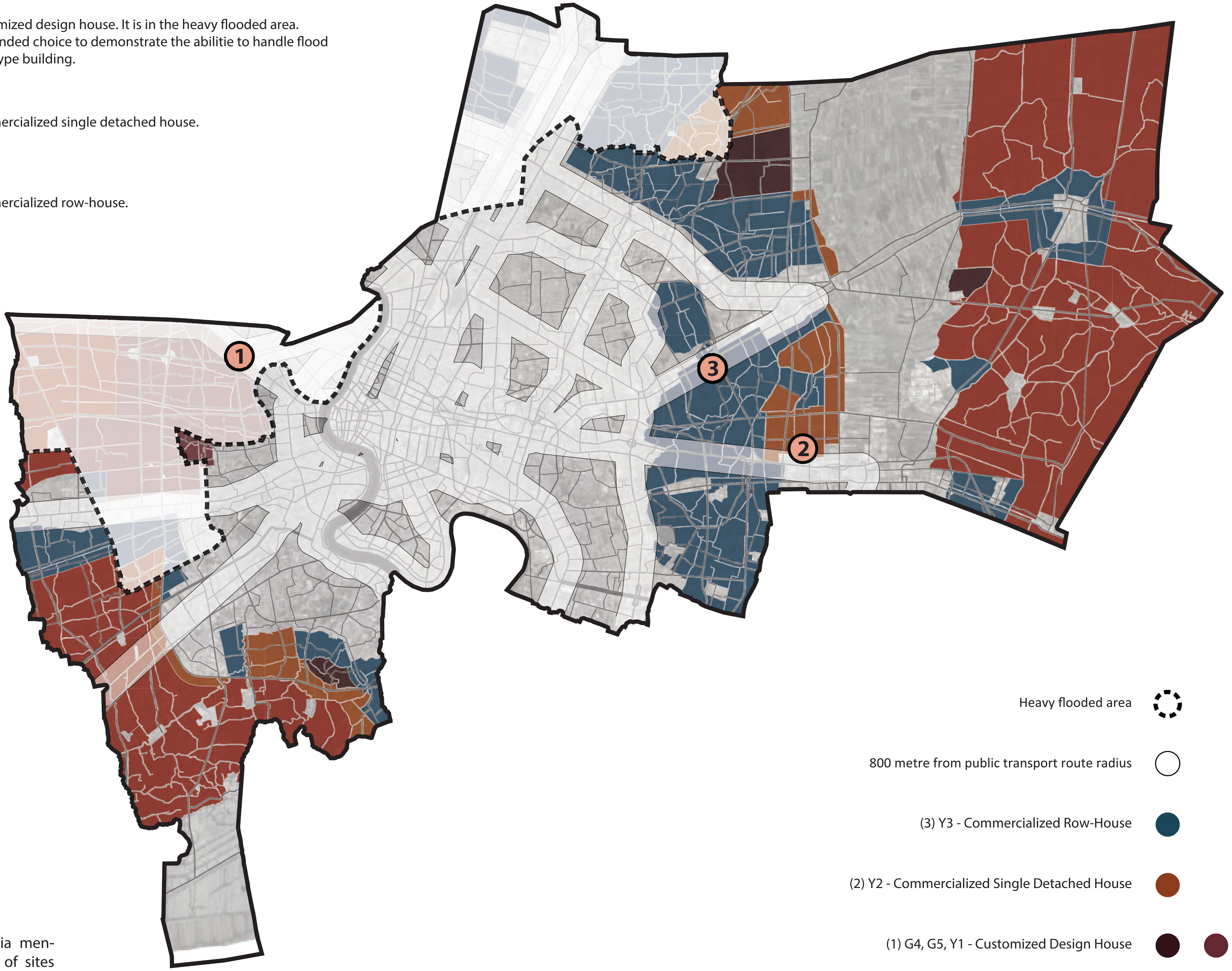
Mass transport

Even though, the criteria of urban zoning and flood area has been established, the potential location for construction sites are still too board and need to be narrowed down further. Continuing with the subject of carbon emission, there are other factors that contribute to this emission in built environment. The use of private vehicle is one such problem. This problem can be mitigated by the use of public transport. However, not all of public transport types are preferable in the context of Bangkok. Based on The INRIX 2016 and 2017 Traffic Scorecard, Thailand has the most congested traffic globally. The more time the vehicles spend in traffic, the more fuel consumed and the more carbon emitted in to the atmosphere. This means that, the public transport that does not occupy roads and streets is a more preferable option. Trains is the type of transport that has already been established as an urban public transport in Bangkok and there are expansive plans for future routes. Therefore, train routes will be an additional criteria for sites location, since it allowed the residents to use a public transport which they can use to avoid congestion and lowered their CO2 emission.

1 Site for customized design house. It is in the heavy flooded area. This is an intended choice to demonstrate the abilitie to handle flood by the prototype building.

2 Site for commercialized single detached house.

3 Site for commercialized row-house.



Prototype building sites

Combining all of the criteria mentioned above, the suitable location of sites has been narrowed down to these locations. These are the selected locations of the site with its corresponding house types.

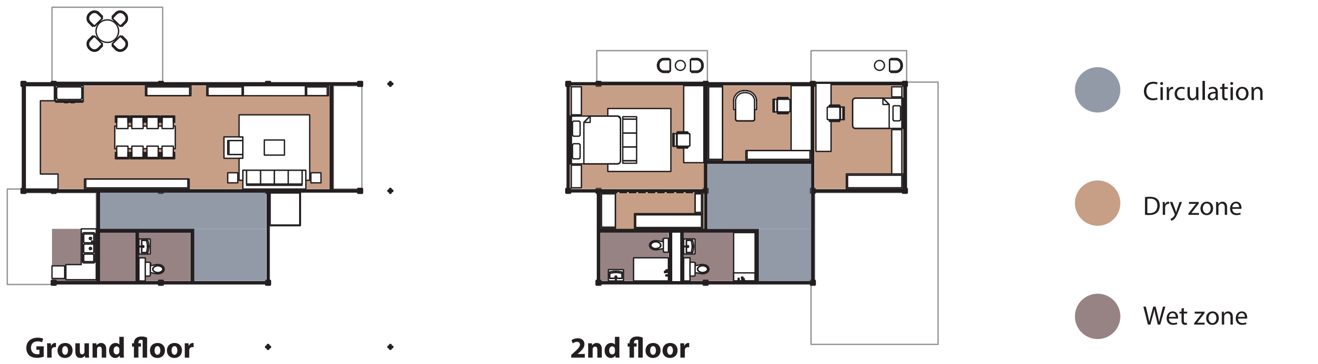
fig 83. Bangkok Street - source: Viriyaroj B.

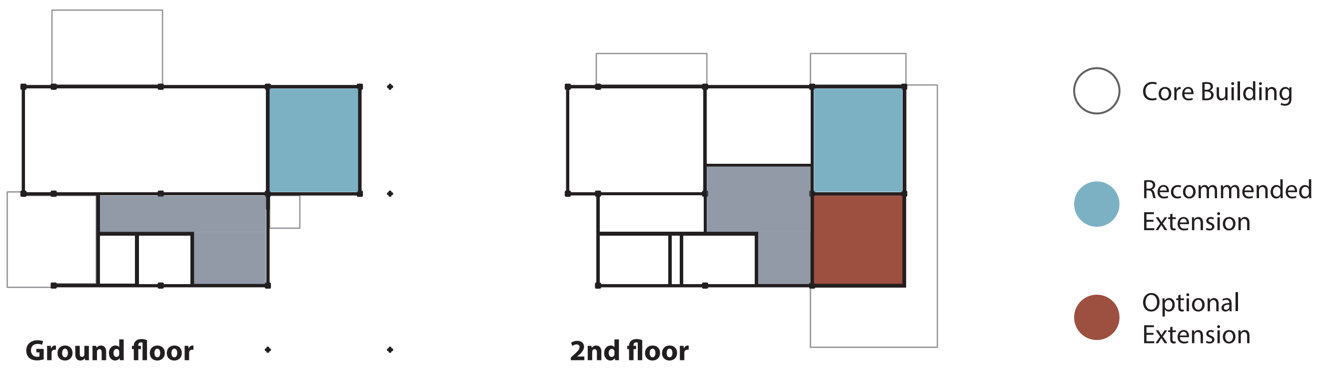
VII. Building design

Commercial detached house

Efficient design

As a commercial house, compact and functionally efficient space will the be most important criteria in house design. In order to achieve the required efficiency, the design will minimize the circulation area of the house. Both on the first and the second floor of the house has one circulation corridor, which all other functional rooms are attached to. The front and back entrance for the residents is also connnected to this circulation corridor. Guest can enter the house through the living area of the house. In addition, this concept of efficiency will be applied to the arrangement of wet zone. All of the wet functions, toilets, showers and kitchen sinks, of both floors are stack on top of one another. This choice of design help saves the number of plumbing pipes in the house. Elevated floor features of this house design also play a role in efficiency concept. Condensing units of air conditioners can be put in the space under the house, which prevent them from being placed on balconies or terraces.

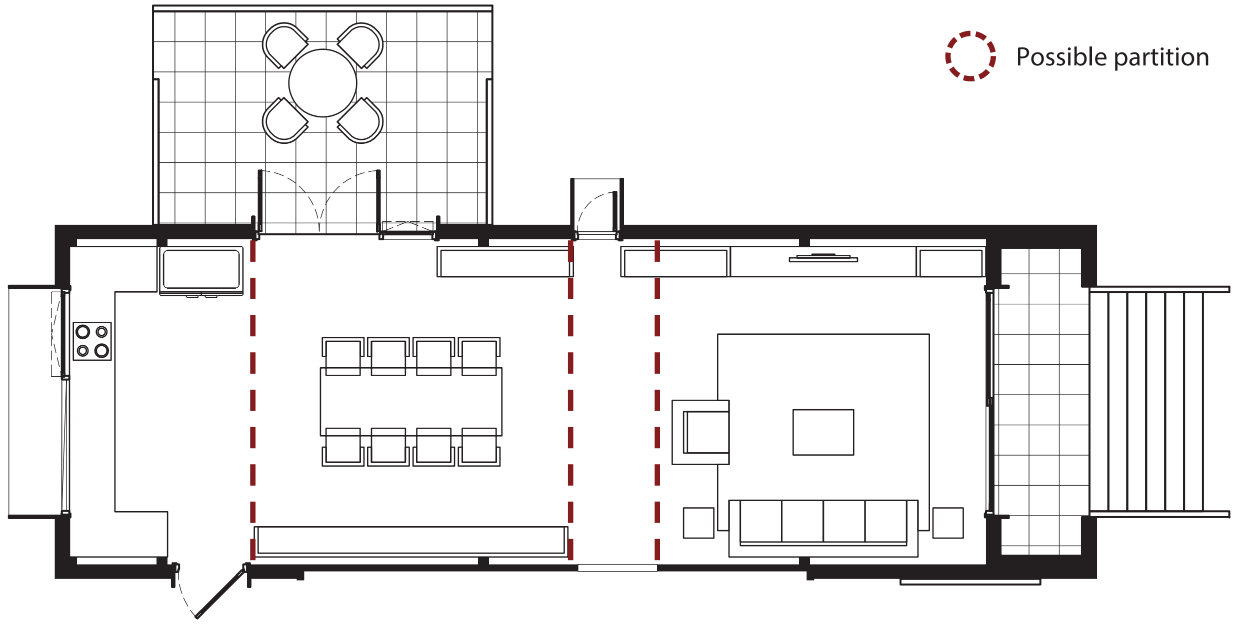




Responding to family dynamics

By employing the concept of disassemble and reassemble, this house can be design with possibility of adjustments to accommodate dynamic family sizes. It is possible for this design to add one extra room on the second floor without disturbing any other function of the building. Furthermore, this house can be built for a smaller family, in order to save initial construction cost. This design can be achieved by removing the bedroom at the frontside of the house. The size of the living room can also be reduced, by removing the first column span near the entrance. These rooms can be added later when the family has grown and require more functional spaces. Wood to steel connection that has been proposed in the previous chapter also help facilitate this expansion.

An additional design choice has also been made to accommodate the concept of responding to family dynamics. The roof of the house is separated into two planes and it take the form of slanted roof. This roof form allowed two sides of the house to be independent from one another. This design feature enables the rooms to be add or remove, with minimum modification to house roof.

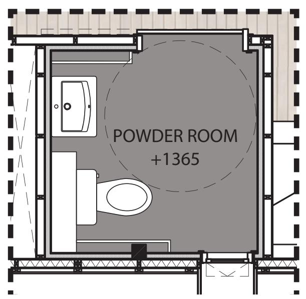


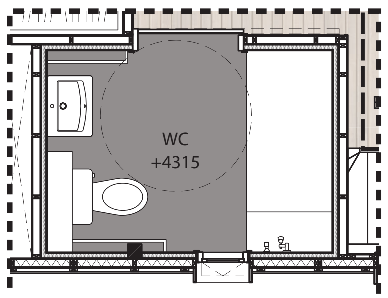
Spacious living area

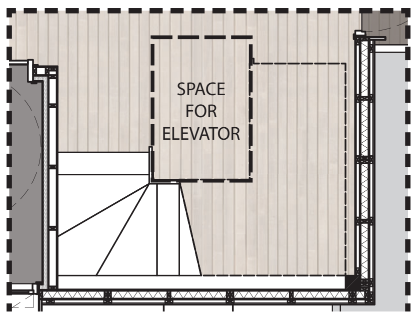
The living area will be combined with the dining area and indoor kitchen. This design choice creates a continuous and spacious living space. The functional use of the living space differs the most in each family, compare to other functions like bedroom or bathroom which require many essential furniture to be functional. This continuous living area enable the room to be flexibly furnished, divided or modified, responding to the unique requirement of each family.

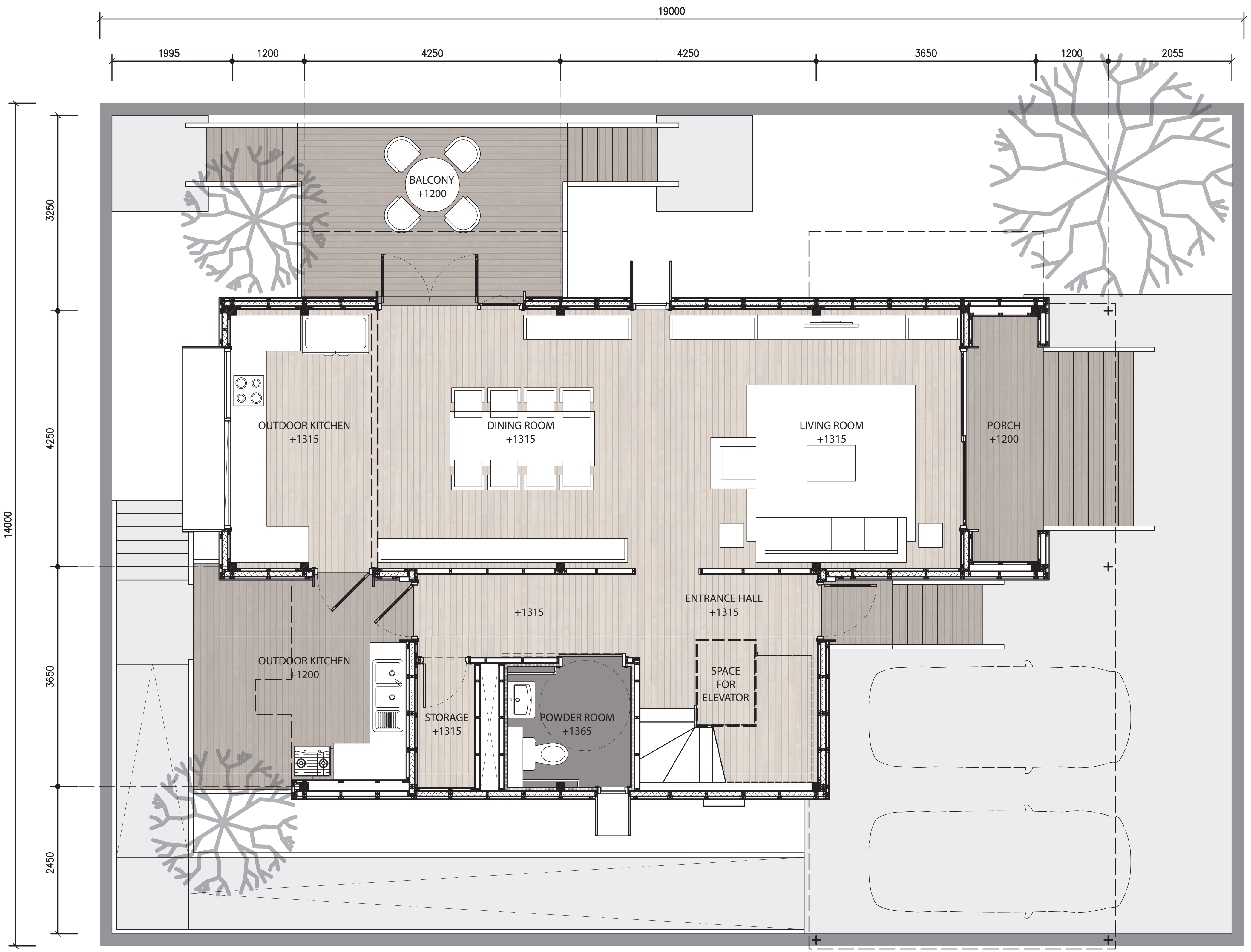
Design for accessibility

In Thailand, the design for accessibility is optional to residential buildings. In order to alleviate the living quality of the house design, this commercial detached house will be equipped with designs that allowed accessibility by wheelchair. Each floor has one bathroom or toilet that can accommodate wheelchair bounded person. This house will also provide a space for hydraulic elevator to be installed for second floor access. There is also a ramp that provide access to the elevated first floor. This ramp lead to the back entrance, which is directly connected to the entrance hall of the house.



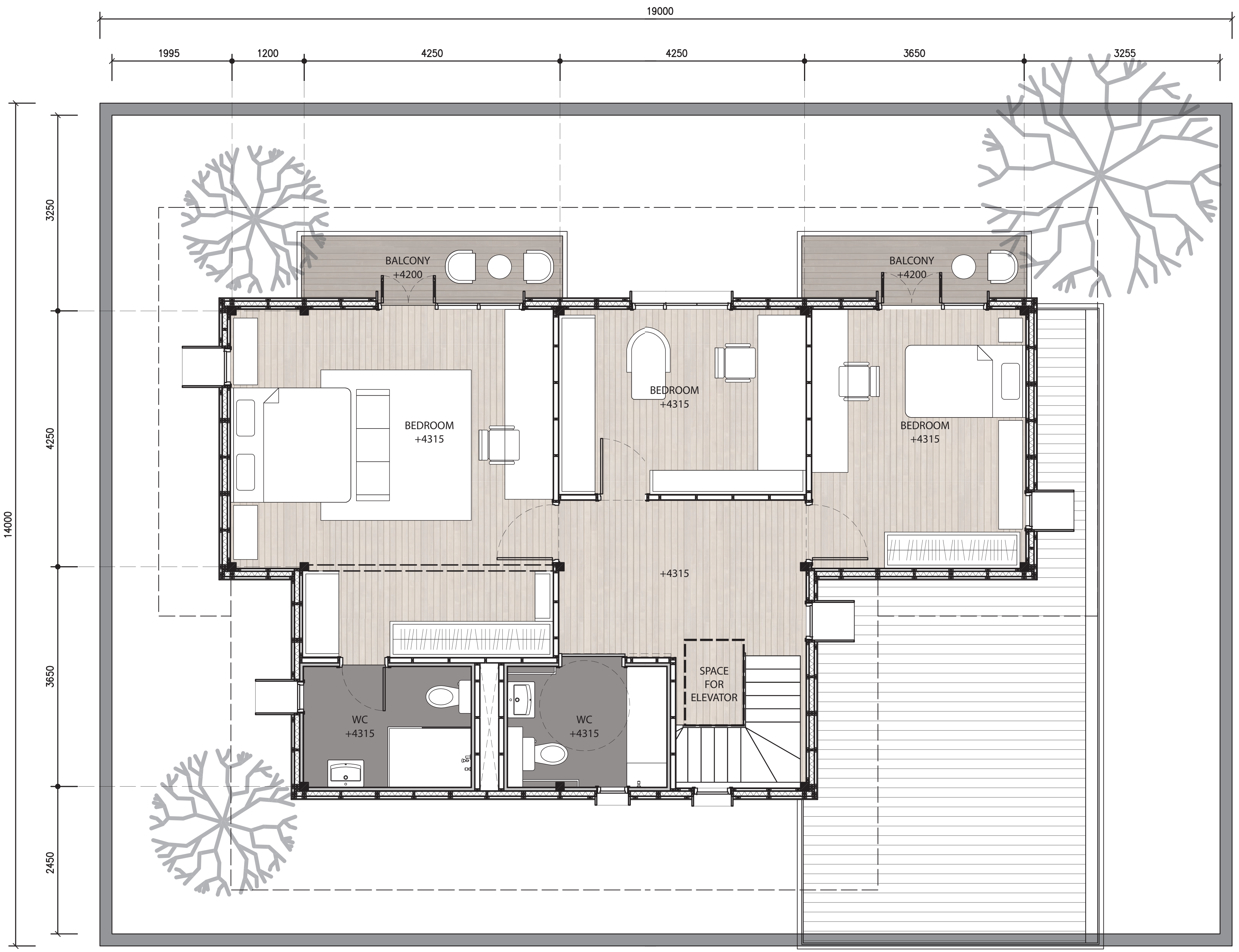






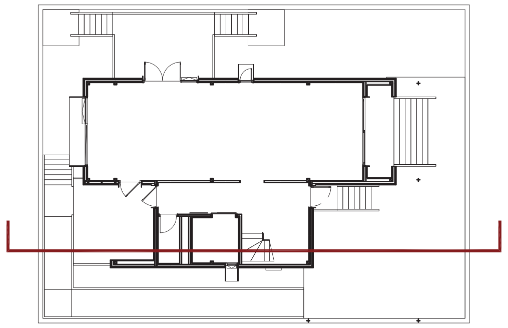
Ground Floor Plan

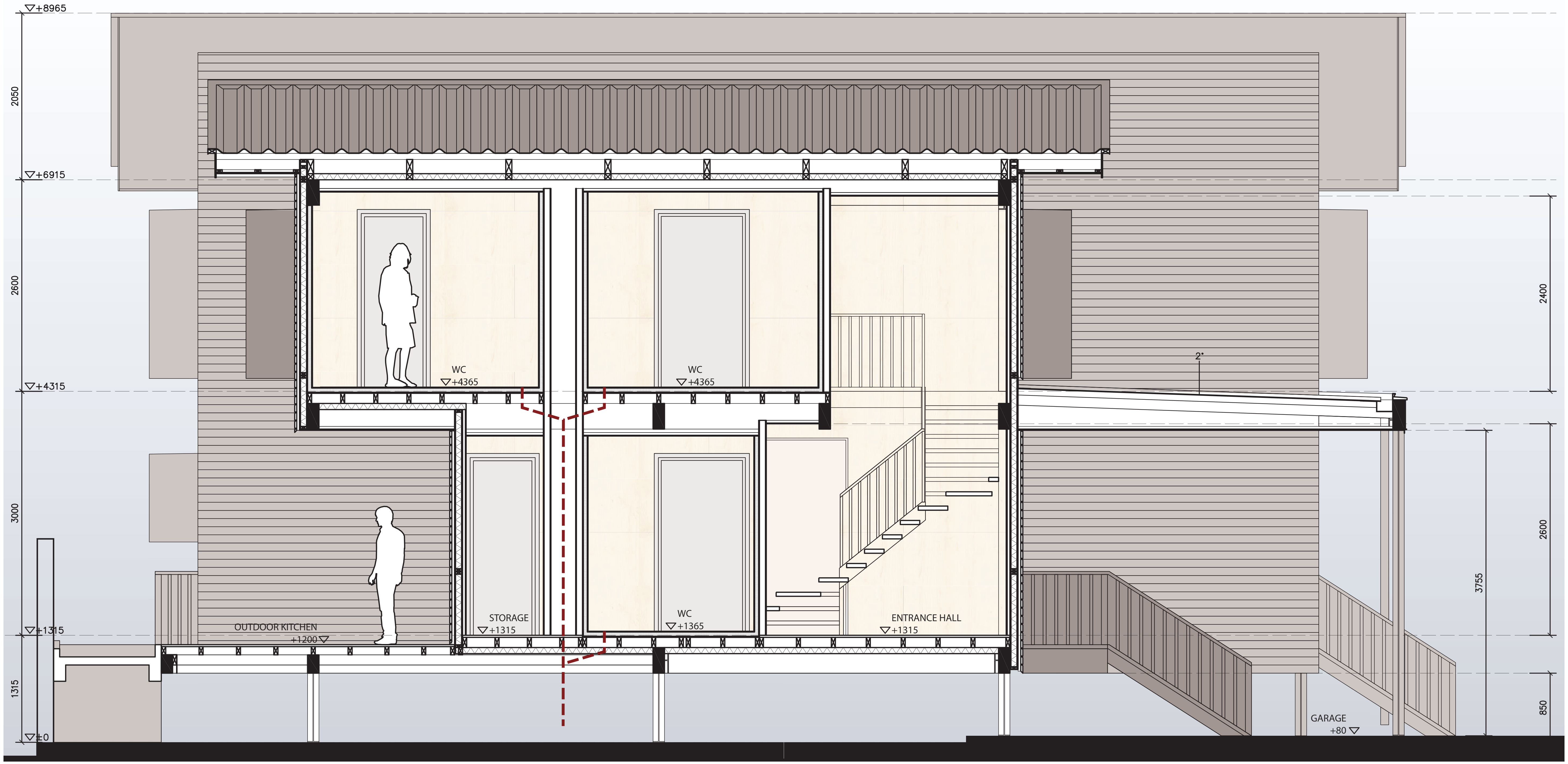
scale 1:75



2nd Floor Plan

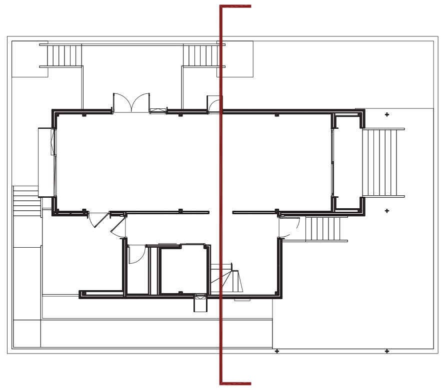
scale 1:75

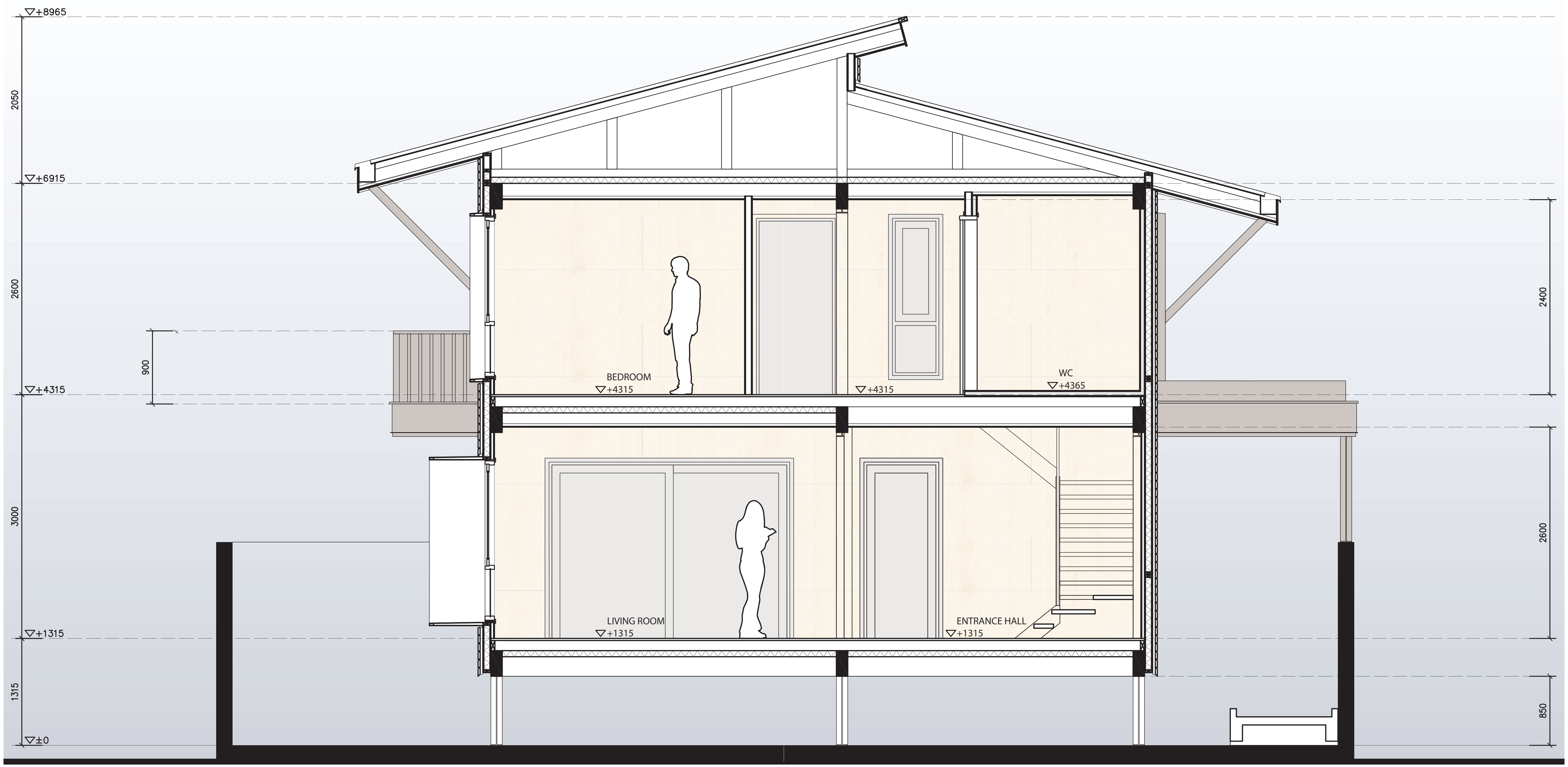




Section 1

scale 1:75





Section 2

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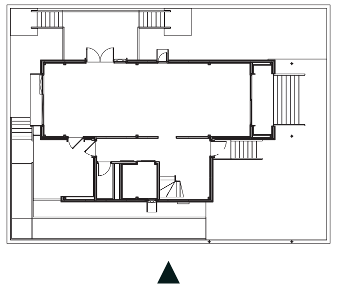

Elevation 1

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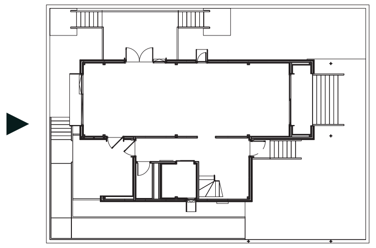

Elevation 2

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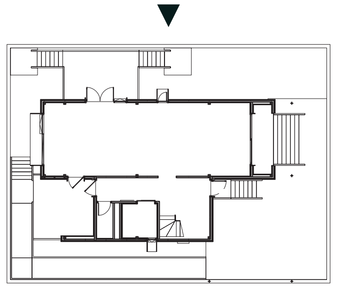

Elevation 3

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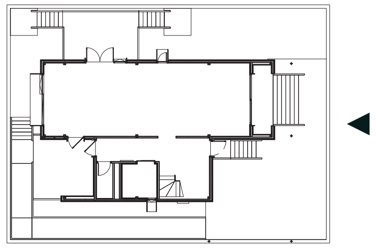
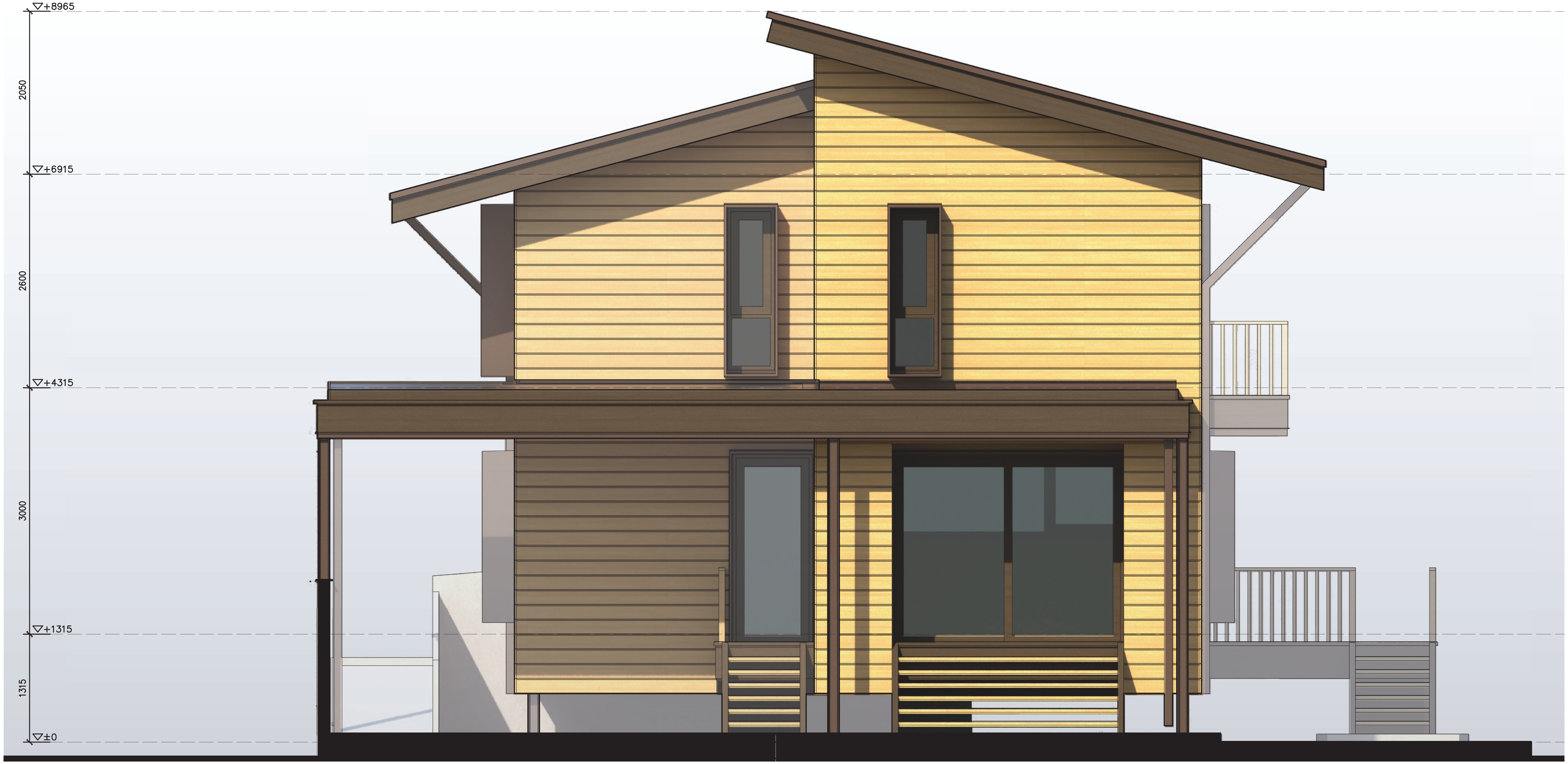
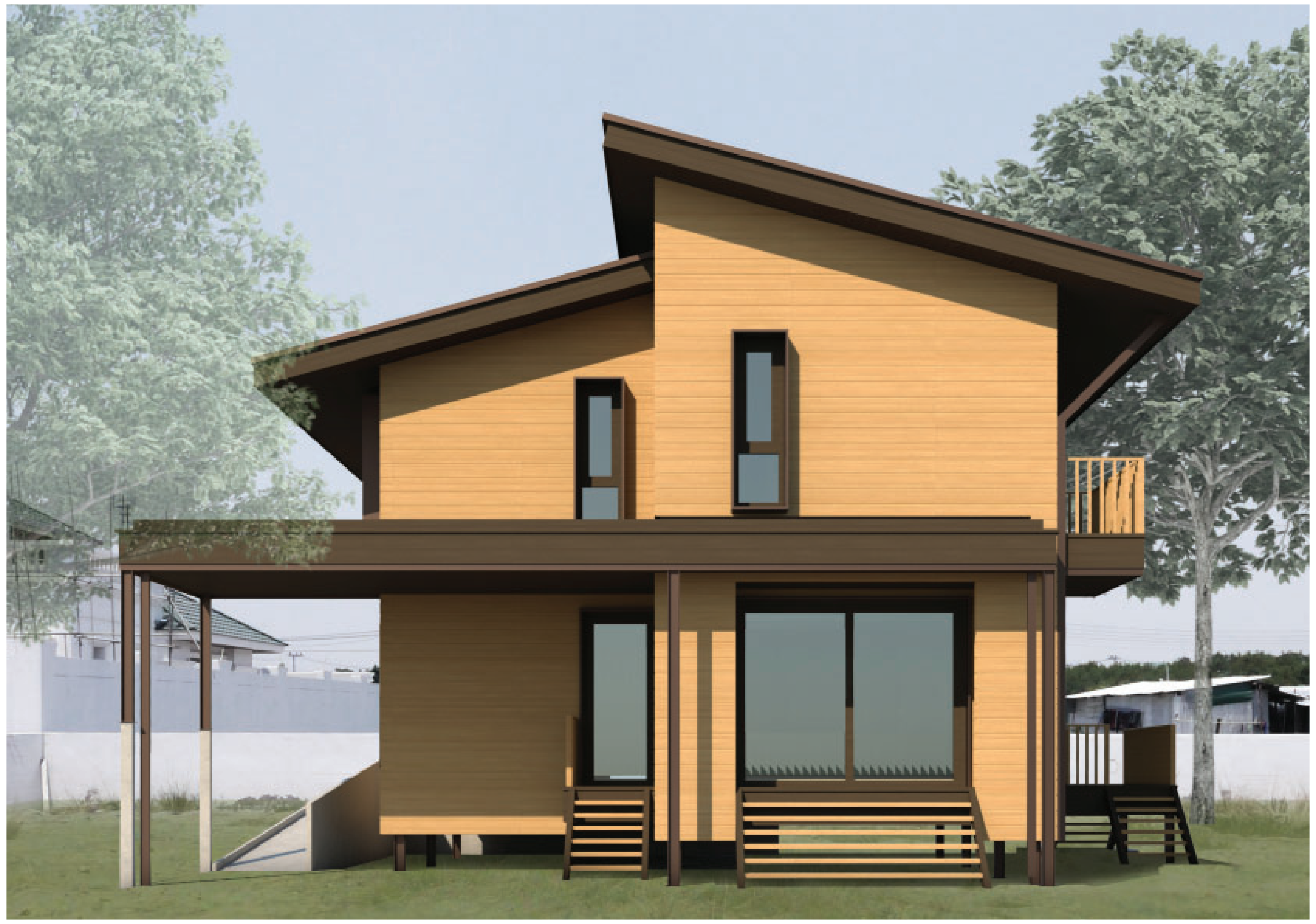




Elevation 4

scale 1:75

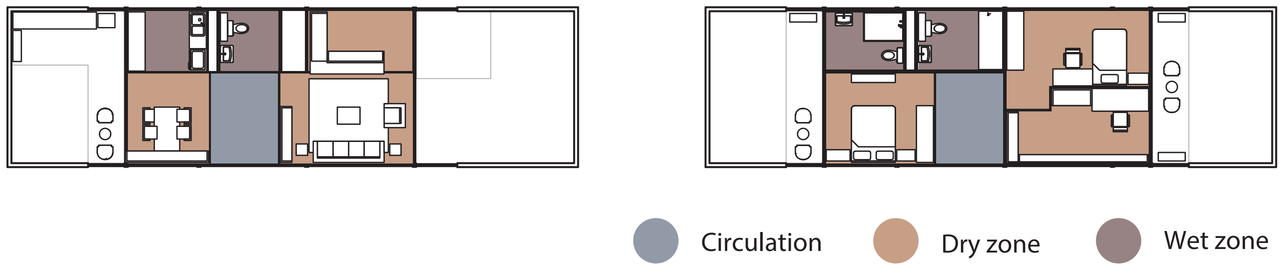


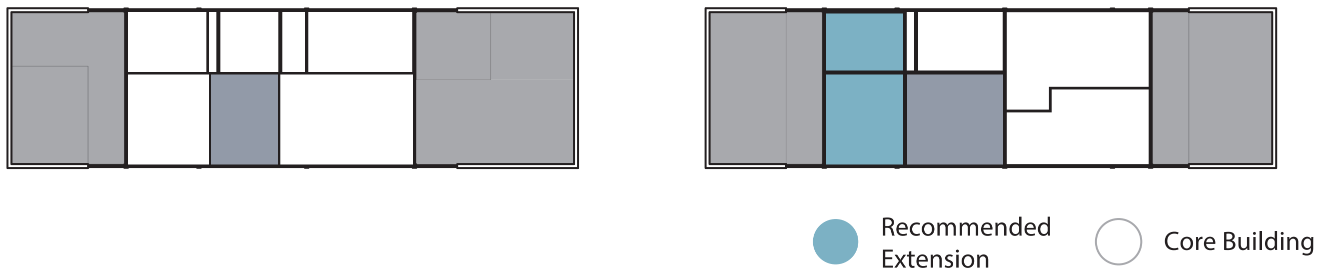
Commercial row house

Efficient design

Achieving functional efficiency in row house is more challenging than detached house, since it has a narrower dimension and only has two side of openable elevations. The idea of one circulation corridor per one floor will be adopted from detach house design, with some modification. Due to its limitations, some part of the first-floor circulation has to be integrated with the living room. The stair is situated at the center of the house, separating the space of dining and living from one another. This position of stair is crucial to the efficiency of functional space, putting it in the central position allowed second floor corridor to be compact, thus giving more spaces to other more important functions.

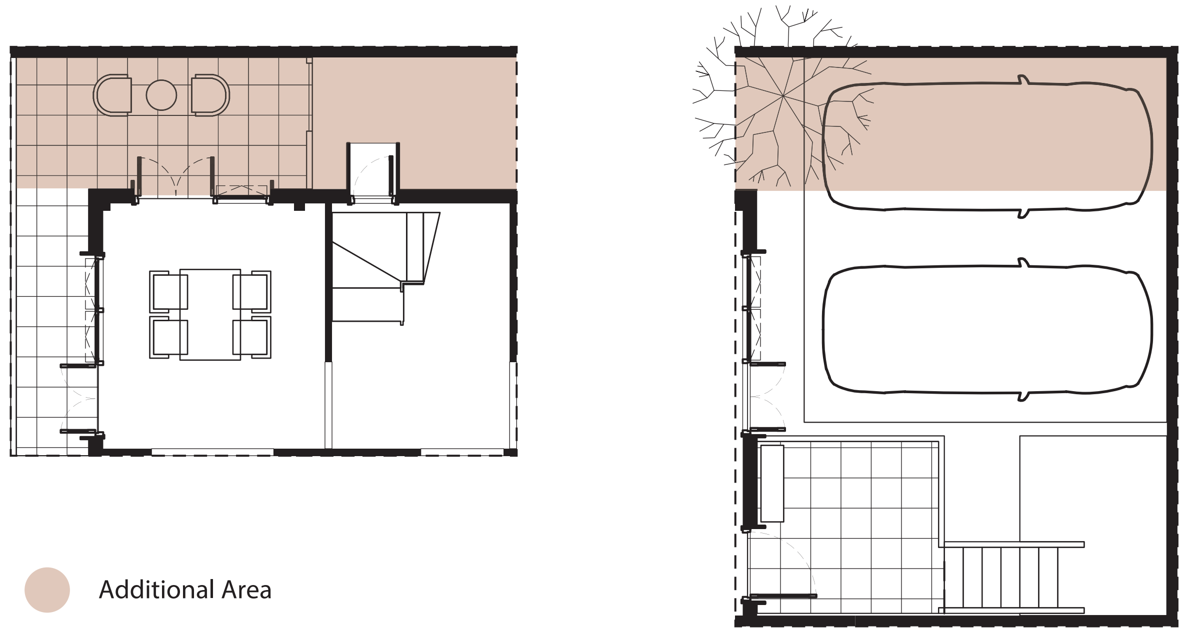
The concept of wet zone grouping that was used in detached house will also be applied in this house type. To further enhance the efficient design, all the toilets and bathrooms in row house has the exact same design as the one in detached house. This decision is chosen to take advantage of prefabrication and replication in commercial projects. Water closets, require numerous fixtures, piping and wiring. Because of its intricate assembly process, it is advantageous to establish standard design of these room and replicate them in several house types. The house in this design is still elevated and the space under the house can be used for placing condensing units of air conditioners.





Responding to family dynamics

Commercial row house can employ the idea of family expansion in a limited degree. For families without children, it is possible to build this house with only one large bedroom or a bedroom with a study. The house can be built without a bedroom at the back of the house, which can then be added later on when an extra bedroom is needed.

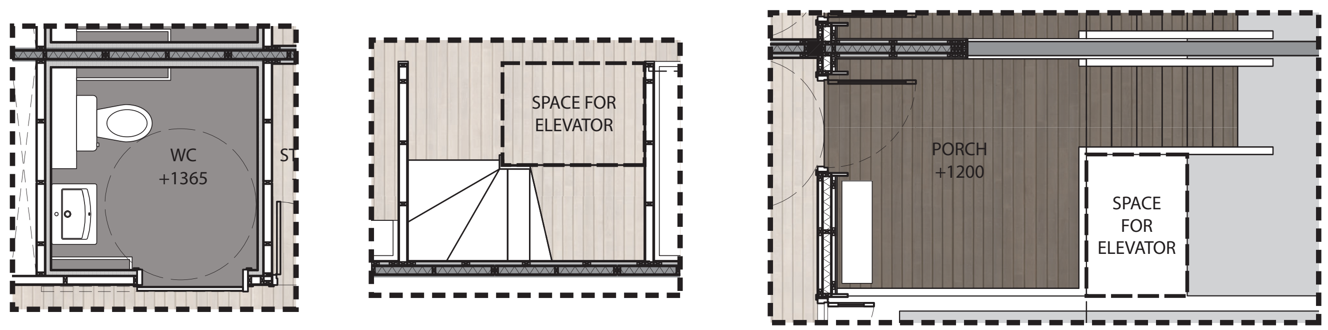


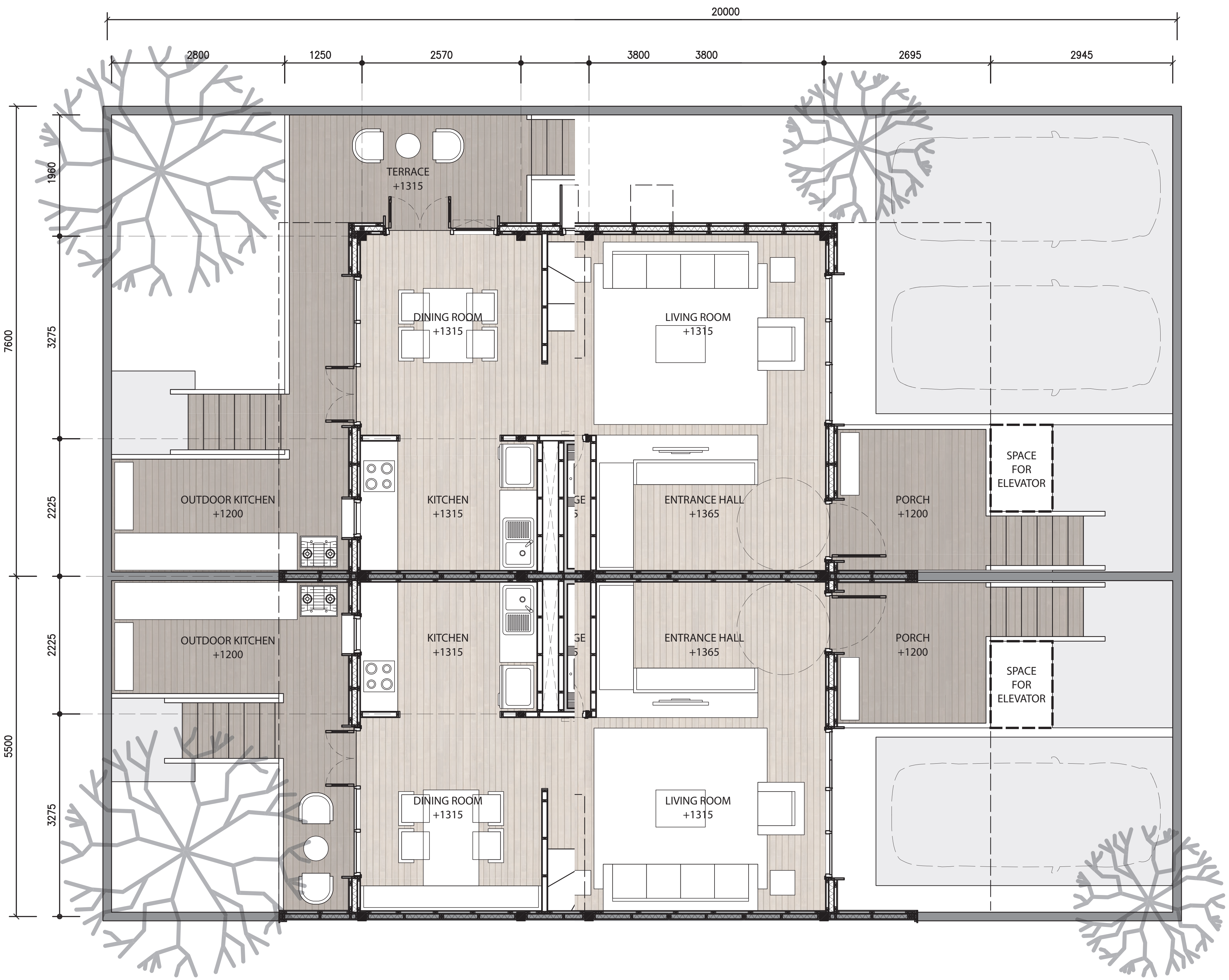
Corner unit

The house at the end of each block has one additional façade and open space. These corner units will have an additional parking spot and extended terrace at the back of the house. Windows will also be installed on the additional façade, providing extra natural light and natural ventilation.

Design for accessibility

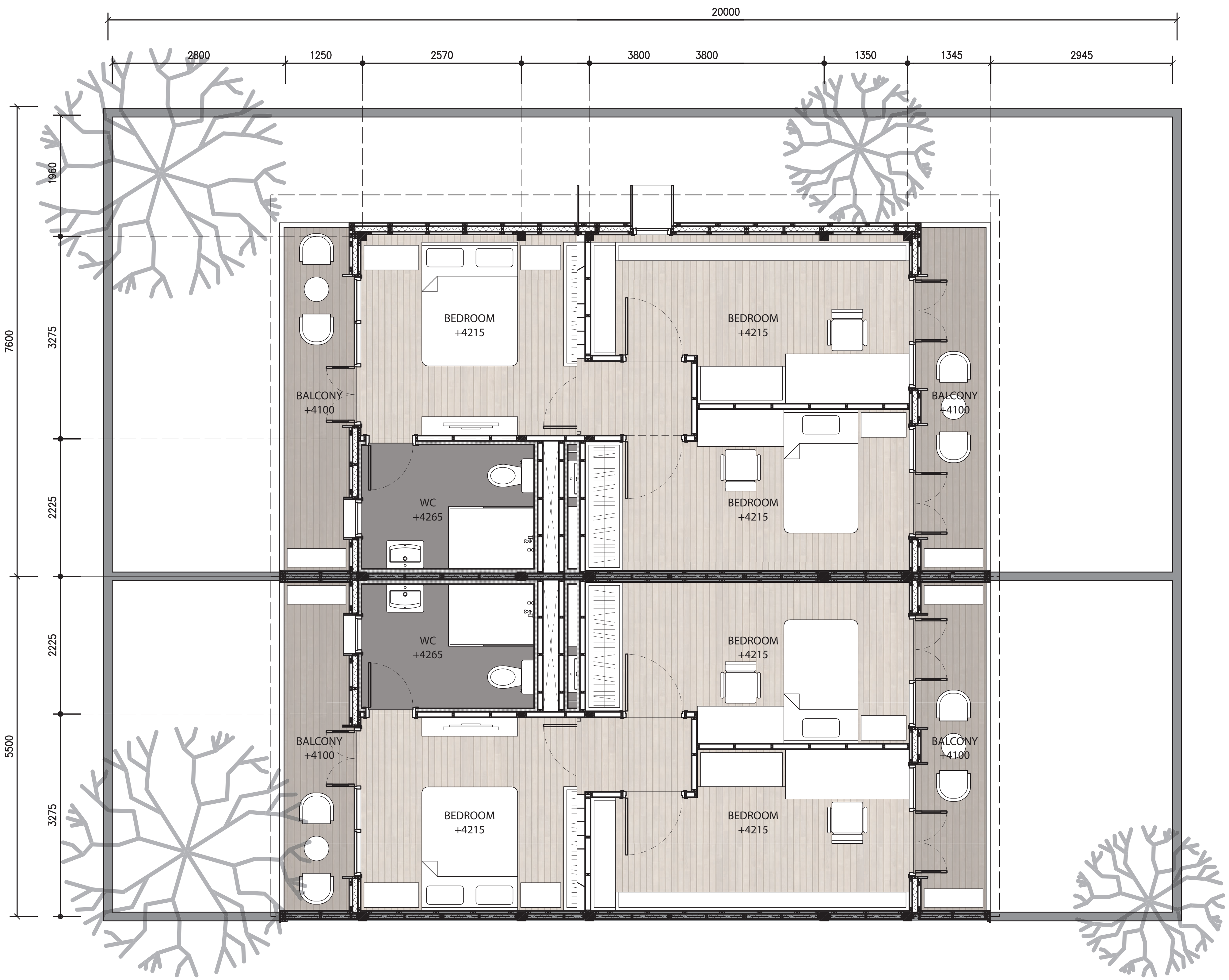
The concept of design for accessibility for this house follow then same steps as the one in commercial detached house. The only difference is its access to first floor. Due to limited size of the land plot, adding ramp to the house is not feasible. The installation of hydraulic elevator can be used to solved this problem and can be attach to the porch of the house.





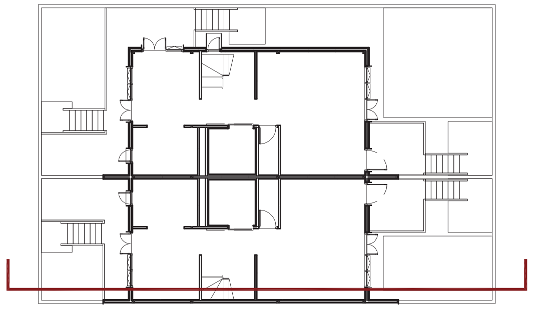
Ground Floor Plan

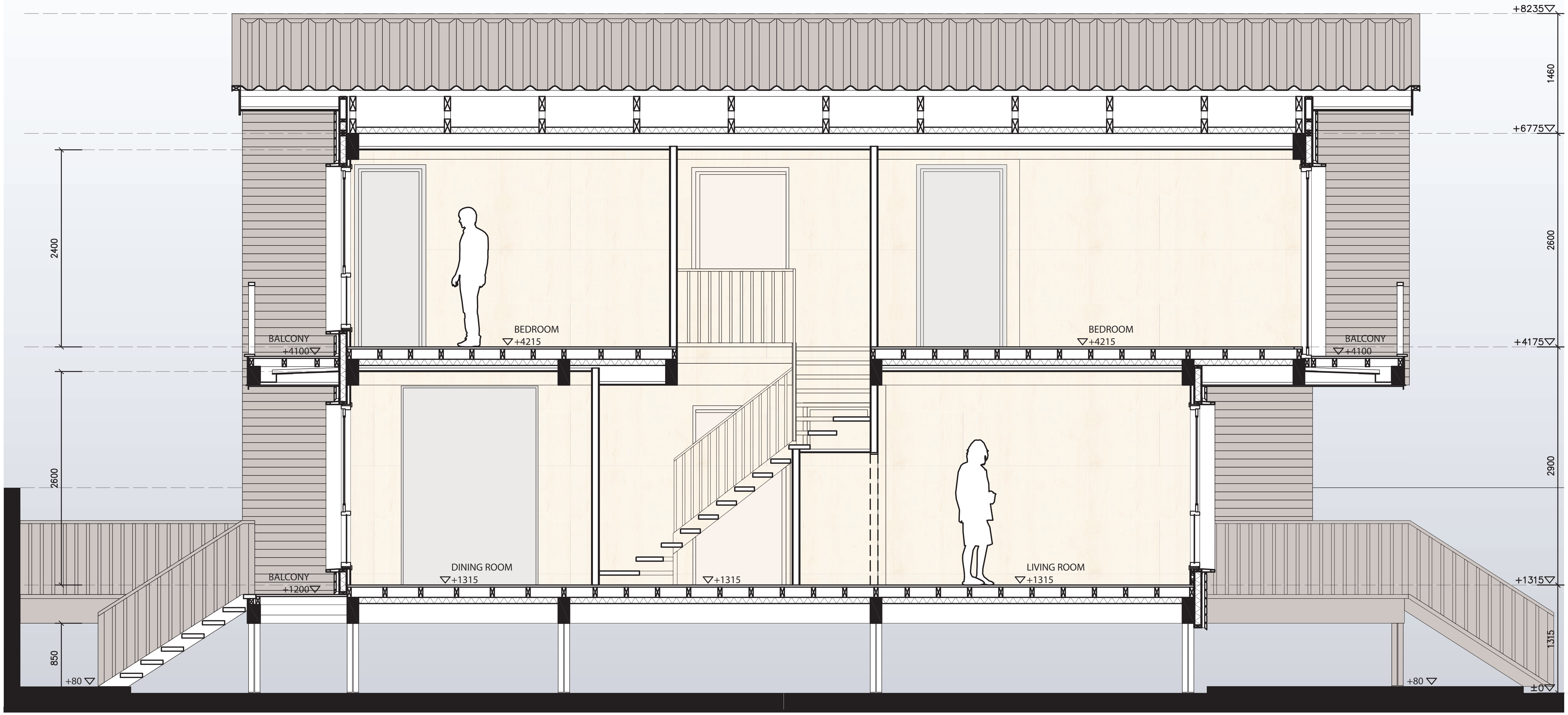
scale 1:75



2nd Floor Plan

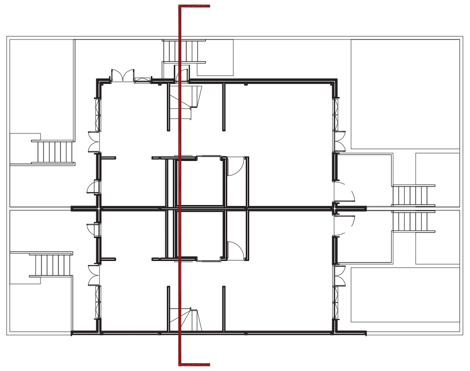
scale 1:75

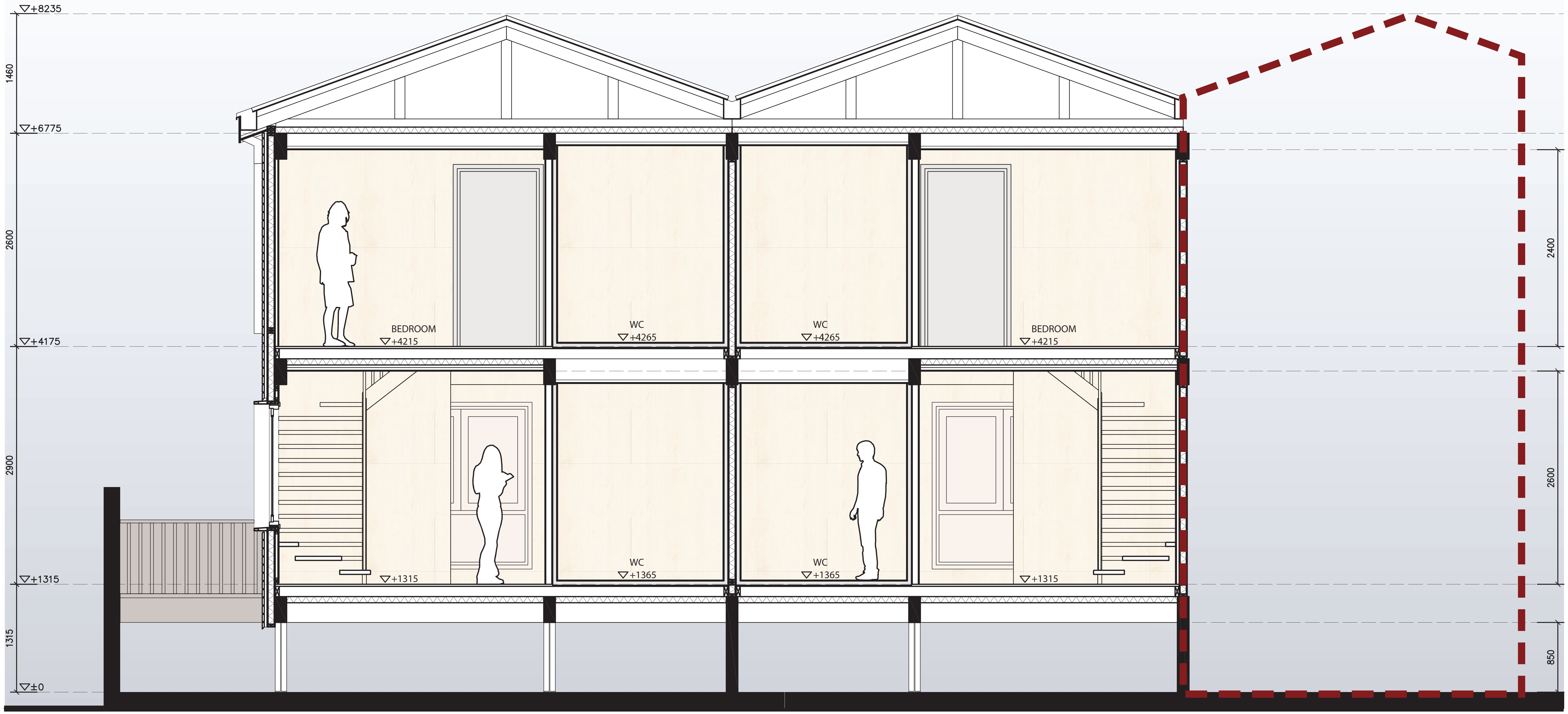




Section 1

scale 1:75





Section 1

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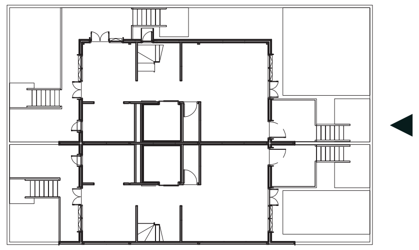
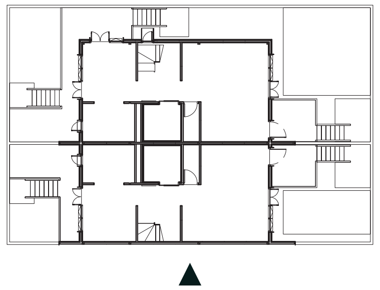


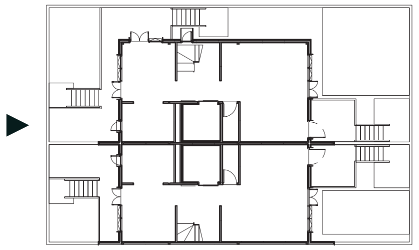
Elevation 1

scale 1:75



Elevation 2

scale 1:75



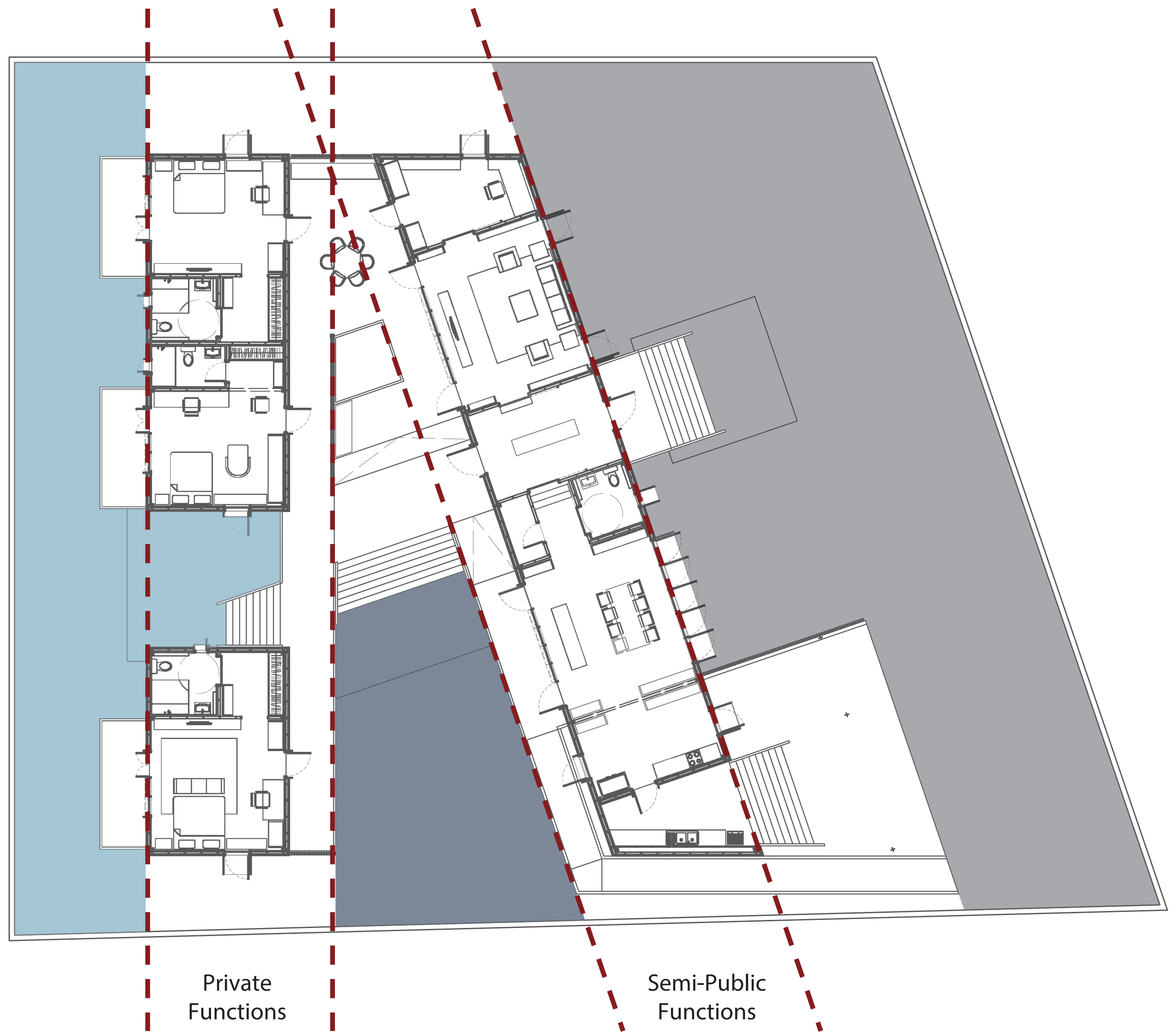
Elevation 3

scale 1:75

Custom design house

Design basis

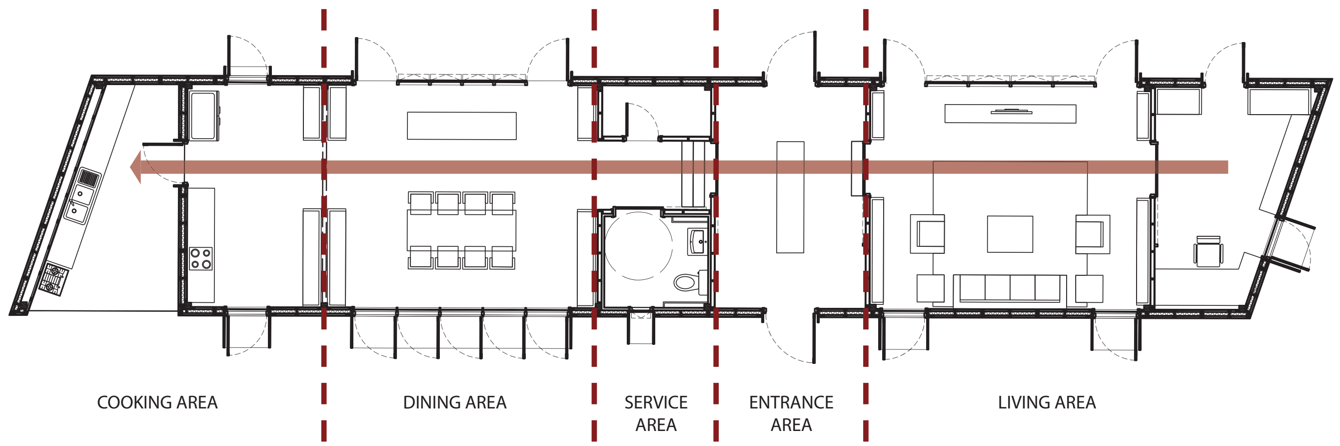
For this house type, I will assume an additional role of another architect that wished to design a custom design house based on "Thai contemporary timber construction system". Modularity is one of the key concepts in the design of "Thai contemporary timber construction system". Using this modularity concept, numerous building designs can be created without redesigning the whole process. However, the concept has drawback of establishing a limitation on the form of architectural design. It restricts the form of buildings with the form of modular units. In the commercial houses, both buildings have cubic form because the modular unit has rectangular geometry. This form limitation has negative impact on the engagement of Thai architects toward the system, since it limits the possibility of their design. "Thai contemporary timber construction system" have to show its lack of this restriction by demonstrating its ability to create a building design outside the geometry of its modular units.



Hybrid contemporary-vernacular Thai architecture

The core design principle in this project is integrating Thai vernacular architecture with the functional use of contemporary architecture. Thai vernacular architecture has flawed in some of its functionality and this design intend to mitigate these flaws, while still maintaining its strength. The functional organization of Thai vernacular will be used for the planning of this house. Functions of the house will be divided in to two groups the semi-public functions and private functions. Semi-public functions consist of living room, dining room, kitchens and study, while all the bedrooms are in the group of private functions. These two functional groups are separated by a central terrace, which also act as an additional outdoor living area. In this design, central terrace will be improved with an addition of terrace roof, making this space usable during rain.

The two functional groups will be aligned linearly, forming two walls that cut the site in to three parts. From these separations, three open spaces will be created. These three open spaces will have its sequence of privacy based on the building sections that separate them. In addition, organizing the semi-public space in a linear form, allowed all of the spaces in semi-public group to be accessible without leaving indoor areas. This convenience is not provided by Thai vernacular architecture, since most of the functions can only be accessed from the central terrace. Toilets and bathrooms are also added as part of the house and can be ysed without leaving the building. In "Ruen Thai" these functions are not inside the house due to their lack of hygiene. However, the issue of toilet hygiene has become obsolete with modern technology, making this isolation no longer necessary.

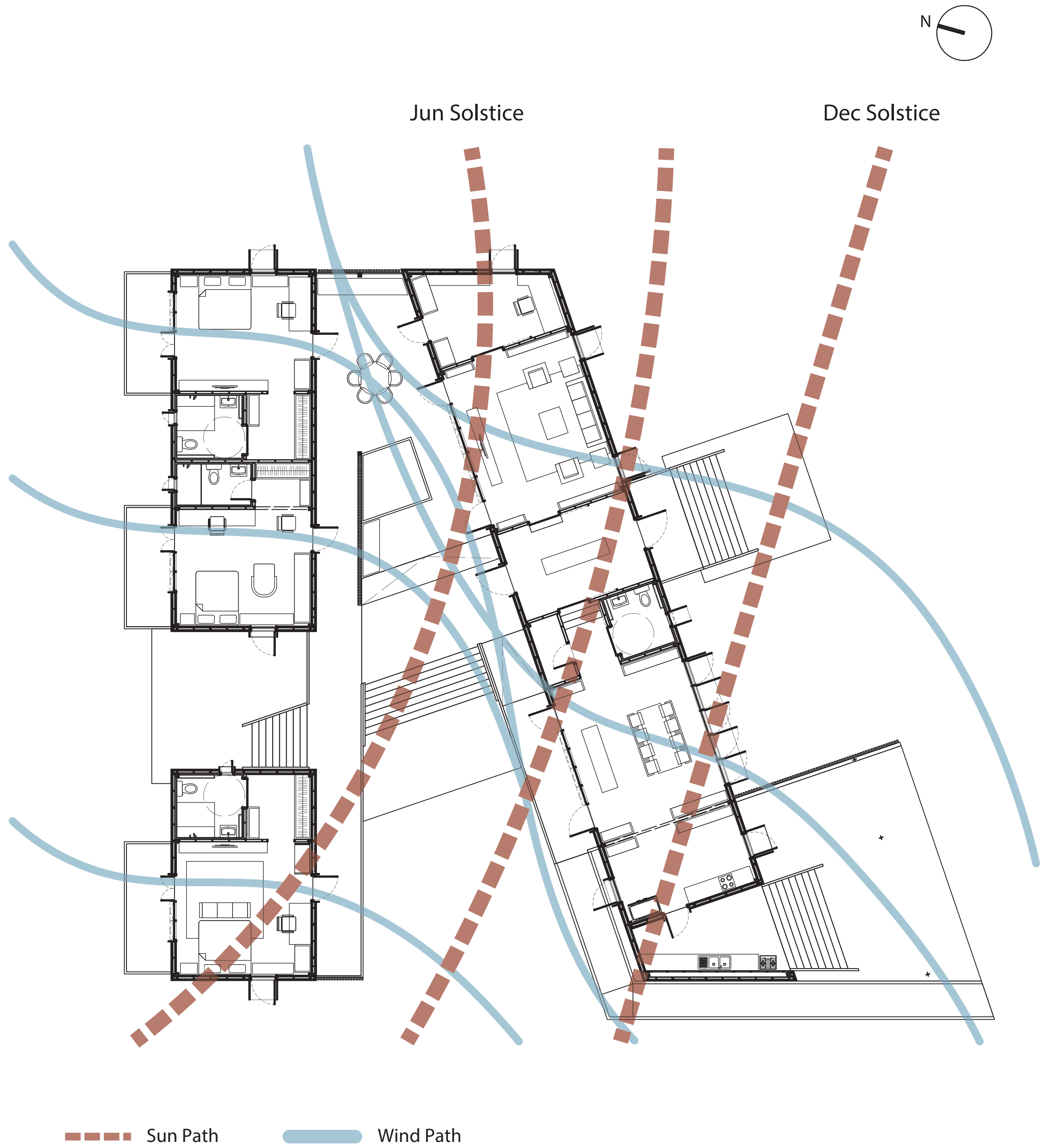


Sequences of space

The entrance of the house has been modified from Thai vernacular architecture. In its original form, the house is accessed through the central terrace. This organization make it difficult to control the privacy of the house, since any room in the building can be freely access by unattended guests. Another drawback for this organization is that, it limits the creation of meaningful sequence of spaces in the house design. In this project, the house will be access through the entrance hall, which can lead to other semi-public spaces. The central terrace can be seen through the entrance hall and living room, creating the feeling of anticipation to the users. The space open up when entering central terrace, where it is directly connected with semi-public garden and form a connection with the environment of this house. Bedrooms can be accessed through the central terrace, making the connection to the nature part of everyday life for the users. These bedrooms are also provided with views to the private garden, further enhancing the connection with nature to the users.

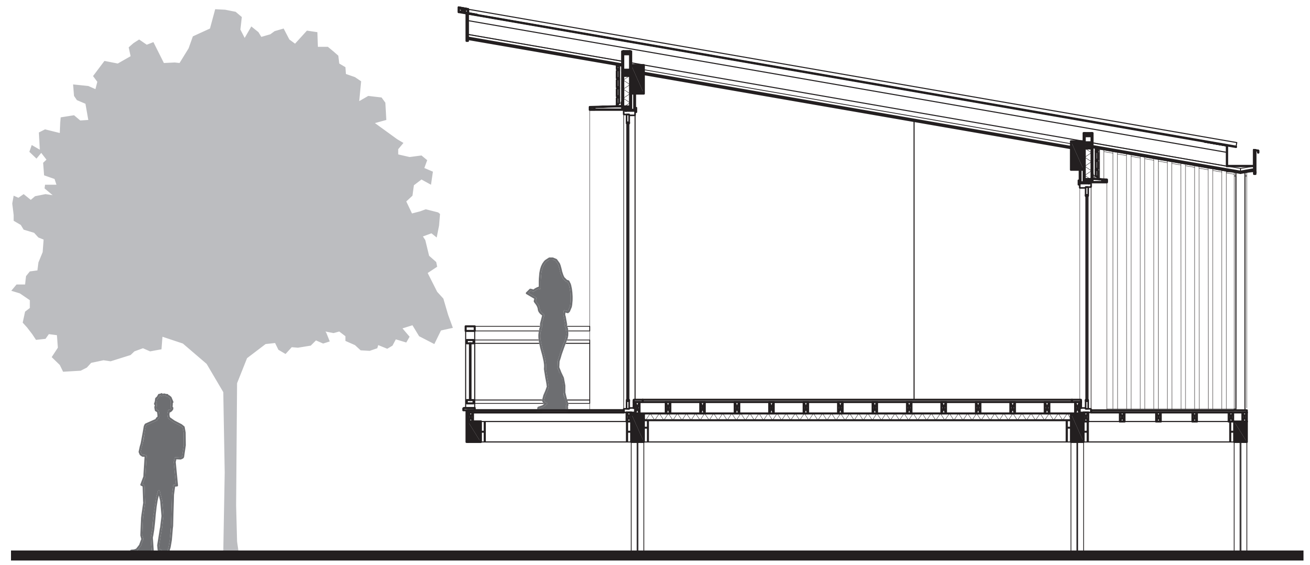
Design for accessibility

The house is elevated and need design for accessibility even though it is a one storey house. A ramp will be installed to provide this access. Other areas of the house that has level differences will be equipped with ramps for wheelchair as well. Most of the bathrooms and toilets has been design for wheelchair access.



House alignment

Alignment of the house is the simplest method of indoor climate control for buildings in Thailand. Sun radiation is the most important factor for maintaining comfortable indoor temperature. East and West façade are the planes that will be heated up the most for buildings in Thailand. For this reason, house in Thailand should align its long façade to face North and South, in order to minimized the effect of sun radiation during day time. Wind is another factor that can be address by building alignment. Fortunately, the direction of the wind in central region of Thailand came from Northeast and Southwest. This means that, the building orientation that mitigate sun radiation exposure also has good access to natural ventilation.

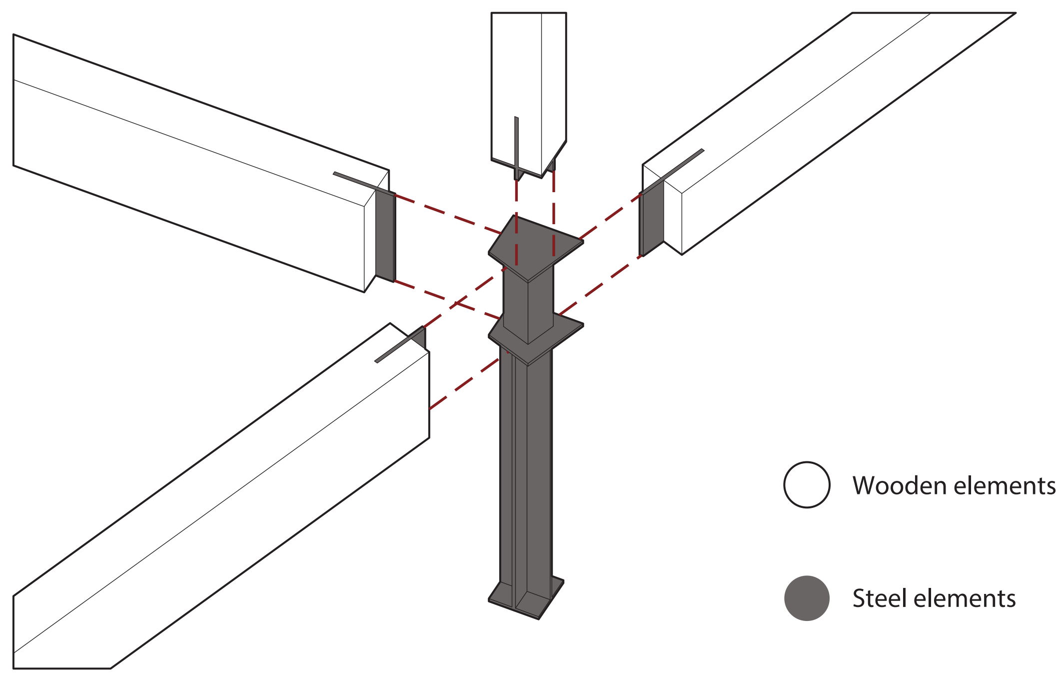


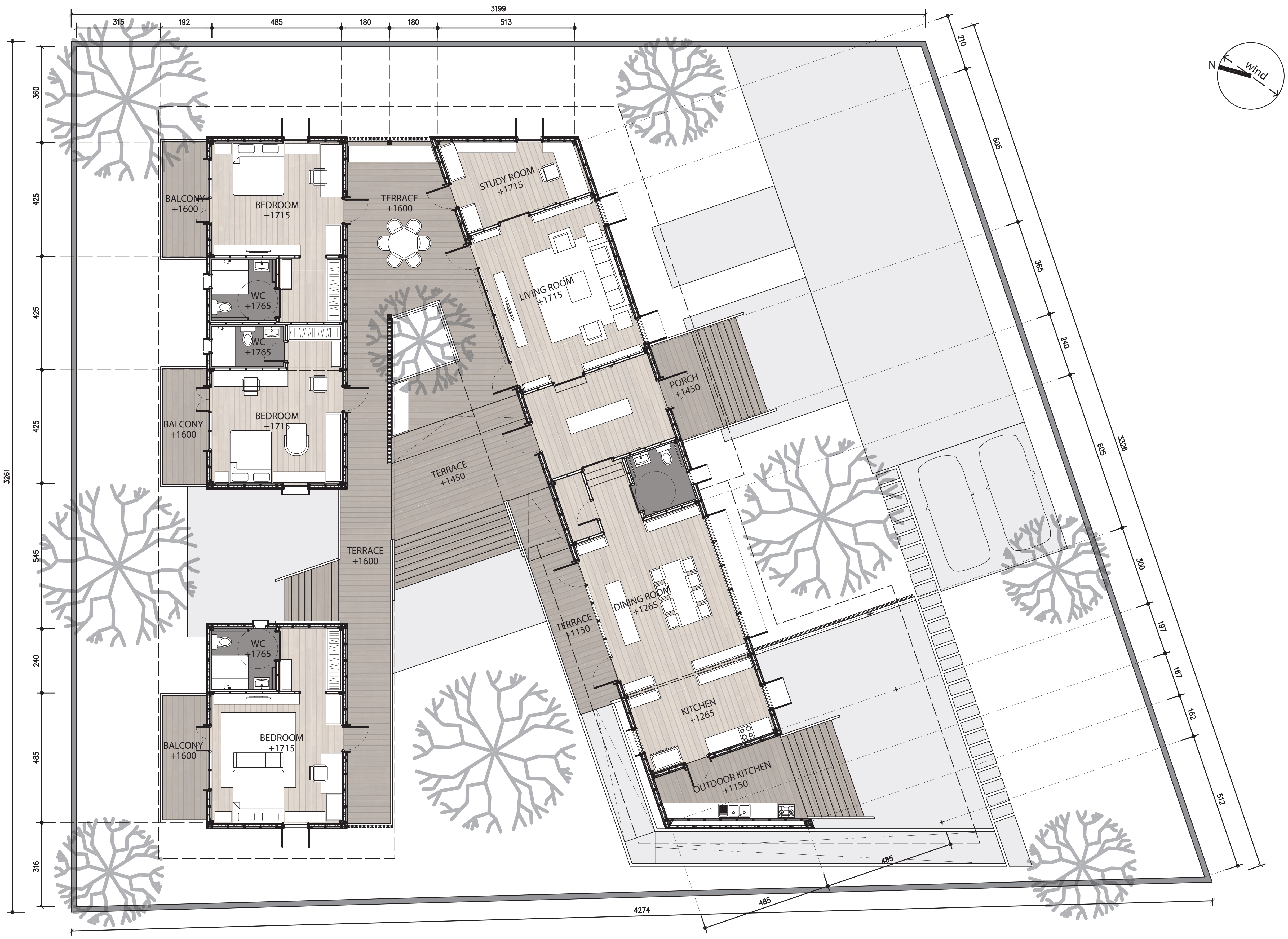
Elevated floor

The height of the elevated floor has been drastically reduced from Thai vernacular architecture. This house is an urban house, and the space for agricultural activities are not needed. These space however, can be used to store condensing units of air conditioner, not unlike the two commercial houses. The elevated floor also allowed bedrooms to retain their privacy even though they are situated on the first floor.

Angular form

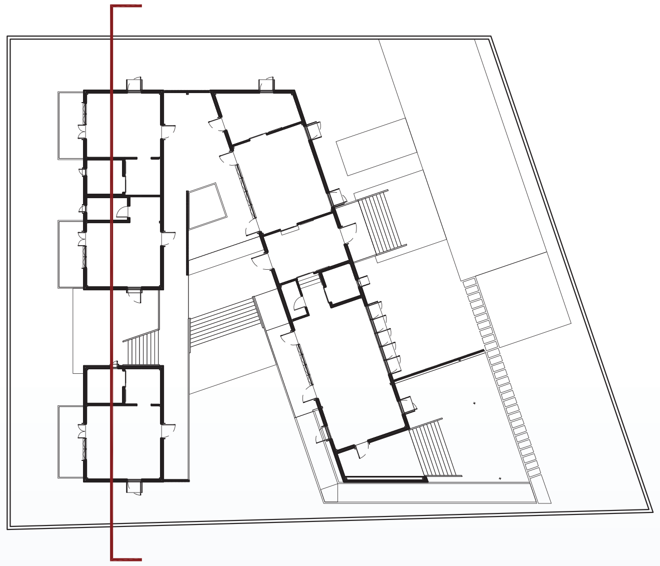
This building employ an angular form vertically and horizontally. This design take advantage of "Core steel joint" detail of "Thai contemporary timber construction system". The "Core steel joint" are modified to be able to connect primary structure in various angle, allowing the building to take the desired shape without creating a new design system.

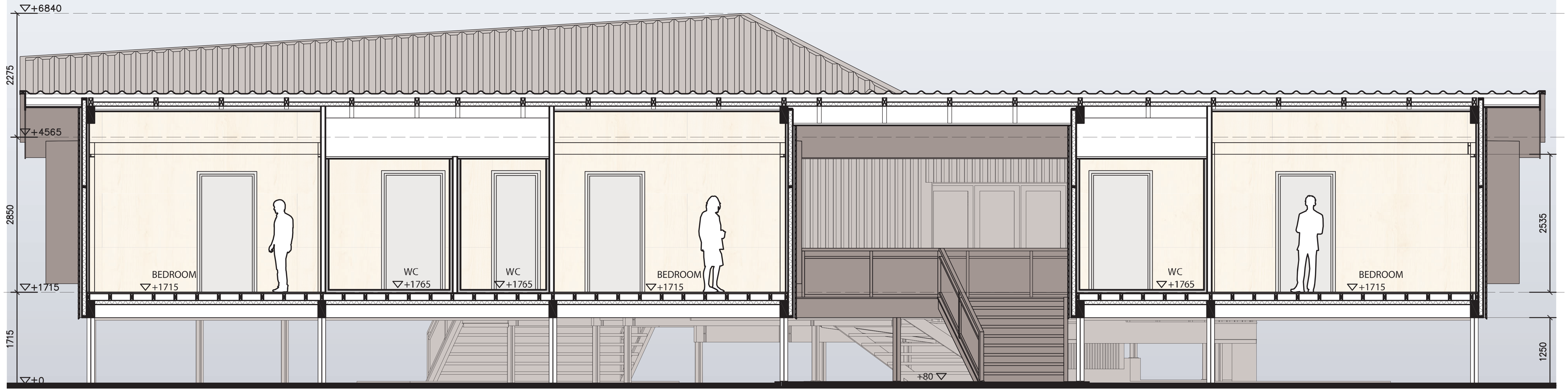




Ground Floor Plan

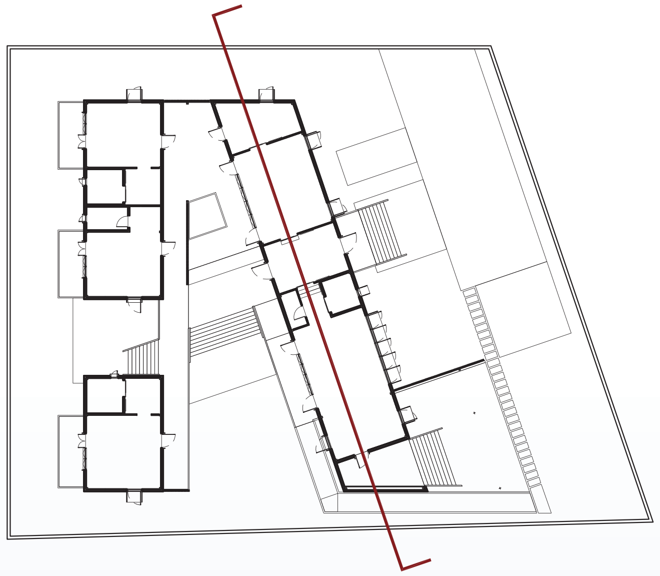
scale 1:150

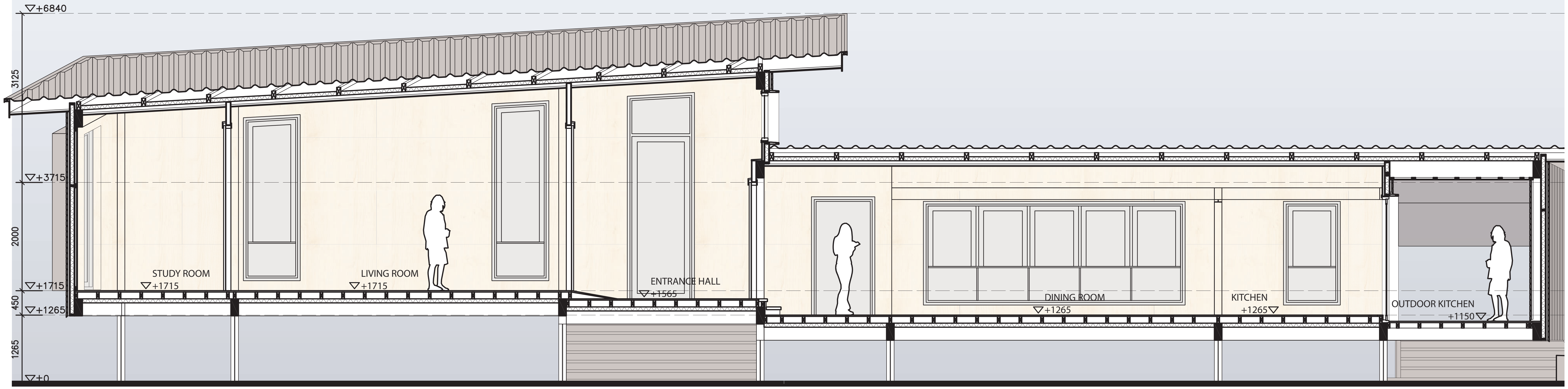




Section 1

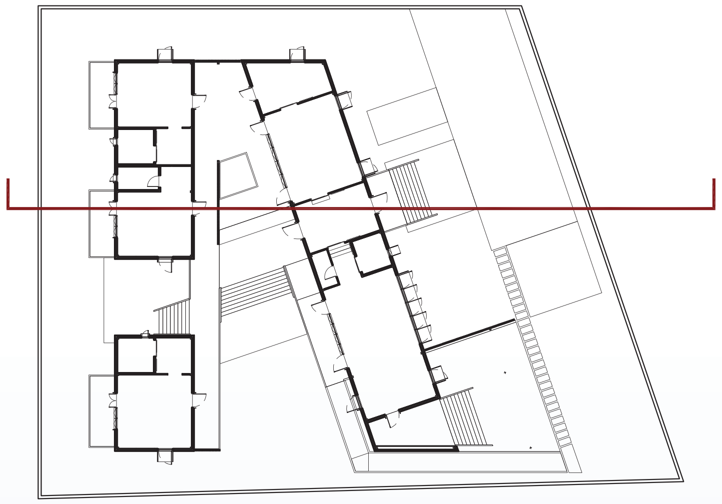
scale 1:75

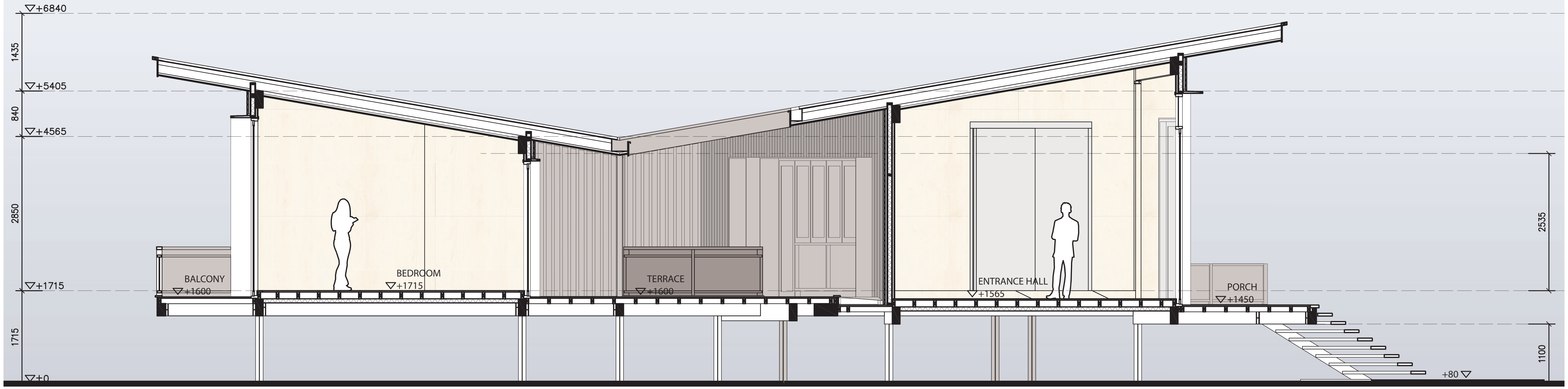




Section 2

scale 1:75



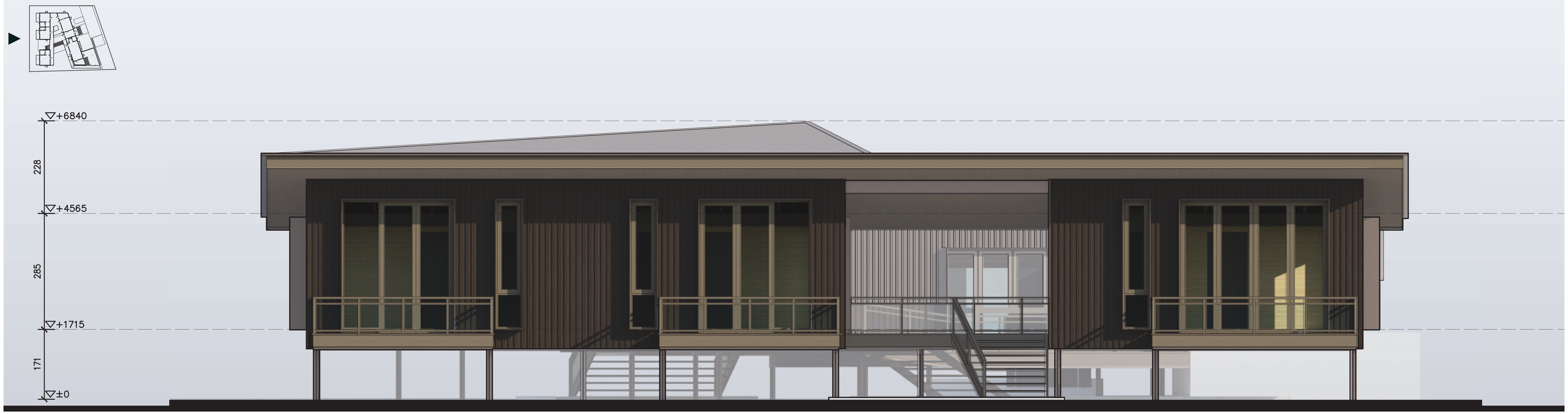


Section 3

scale 1:75

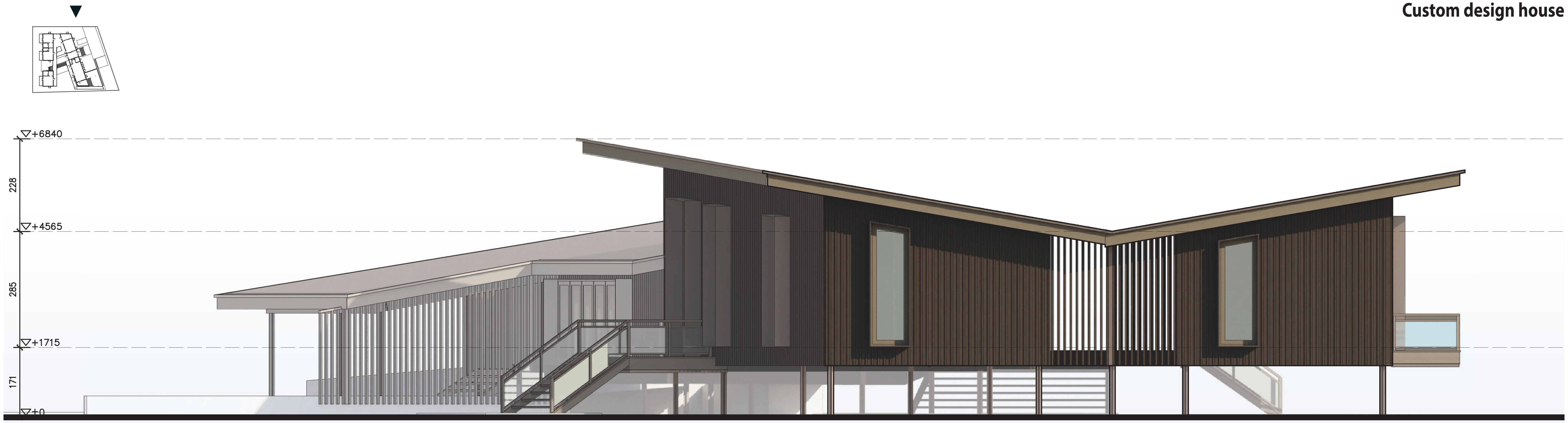
Elevation 1

scale 1:100



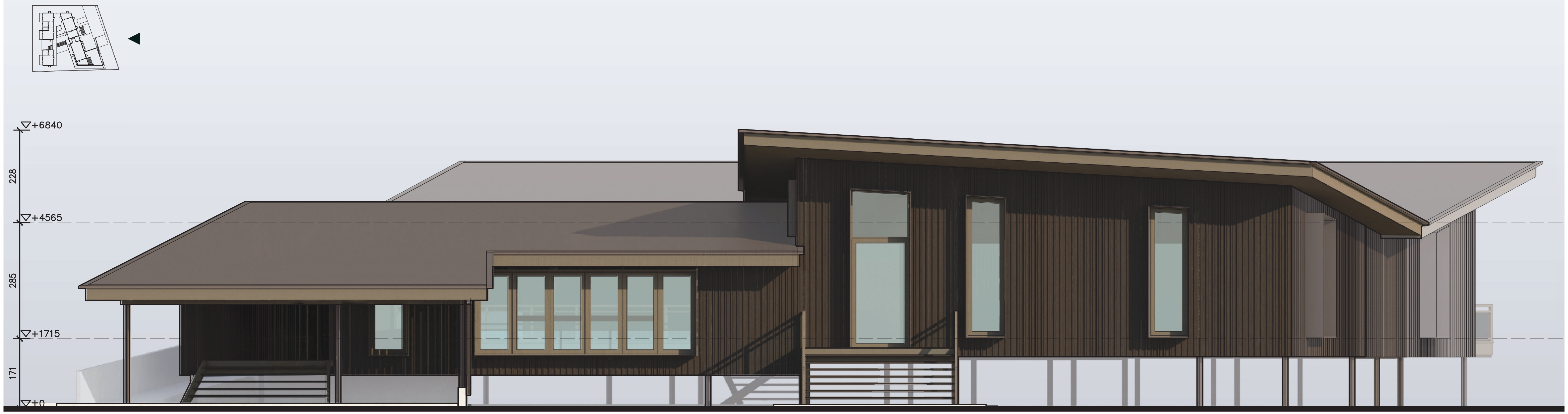
Elevation 2

scale 1:100



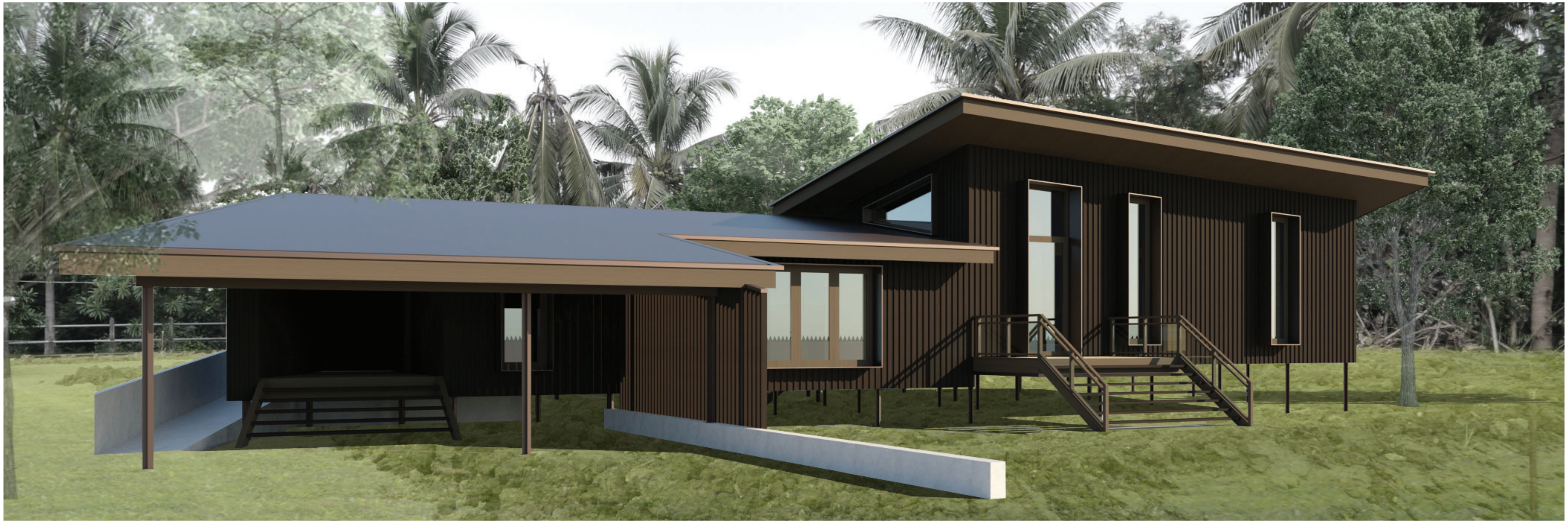
Elevation 3

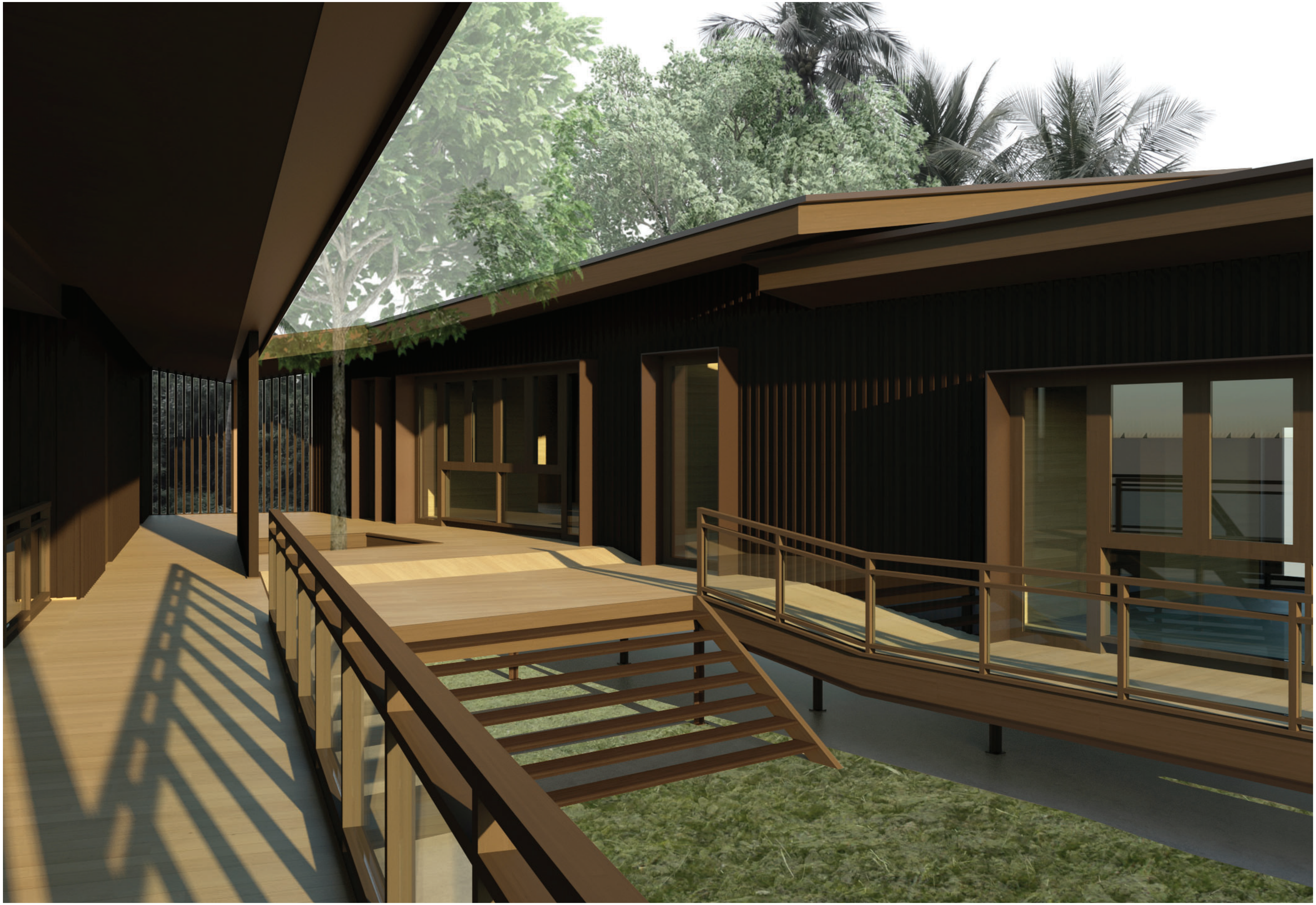
scale 1:100



Elevation 4

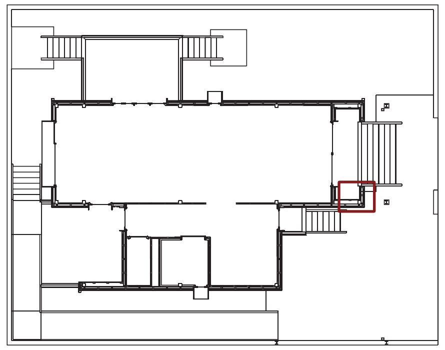
scale 1:100





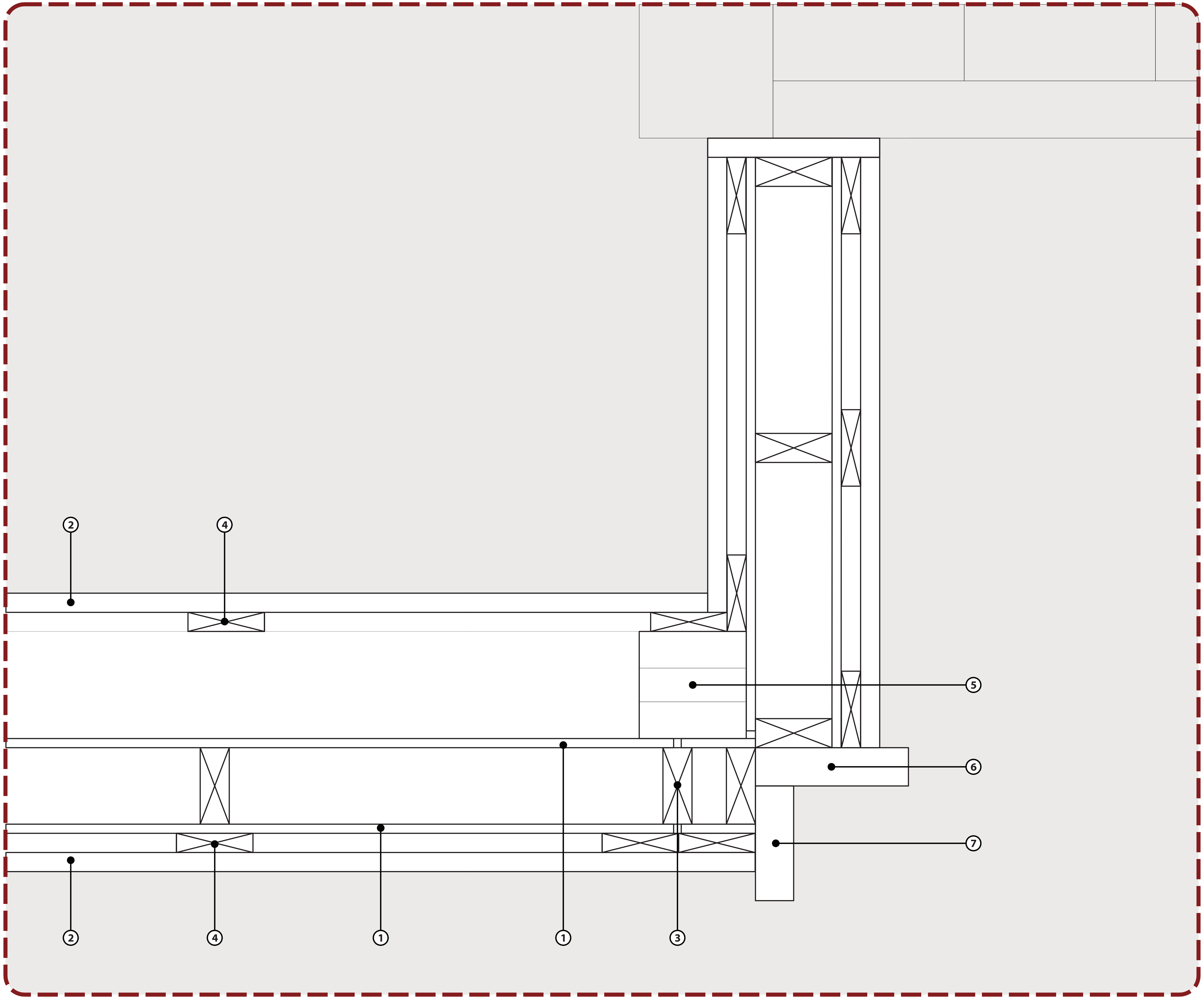
Building details

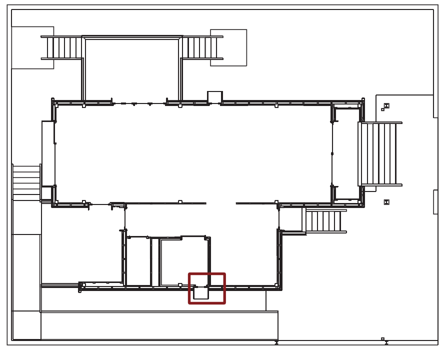
The construction details of all three houses are shared base on "Thai contemporary timber construction system" . All the construction details that will be displayed are taken from Commercial detached house. This is done in order to show some of the detail executed from the utilization of "Thai contemporary timber construction system".

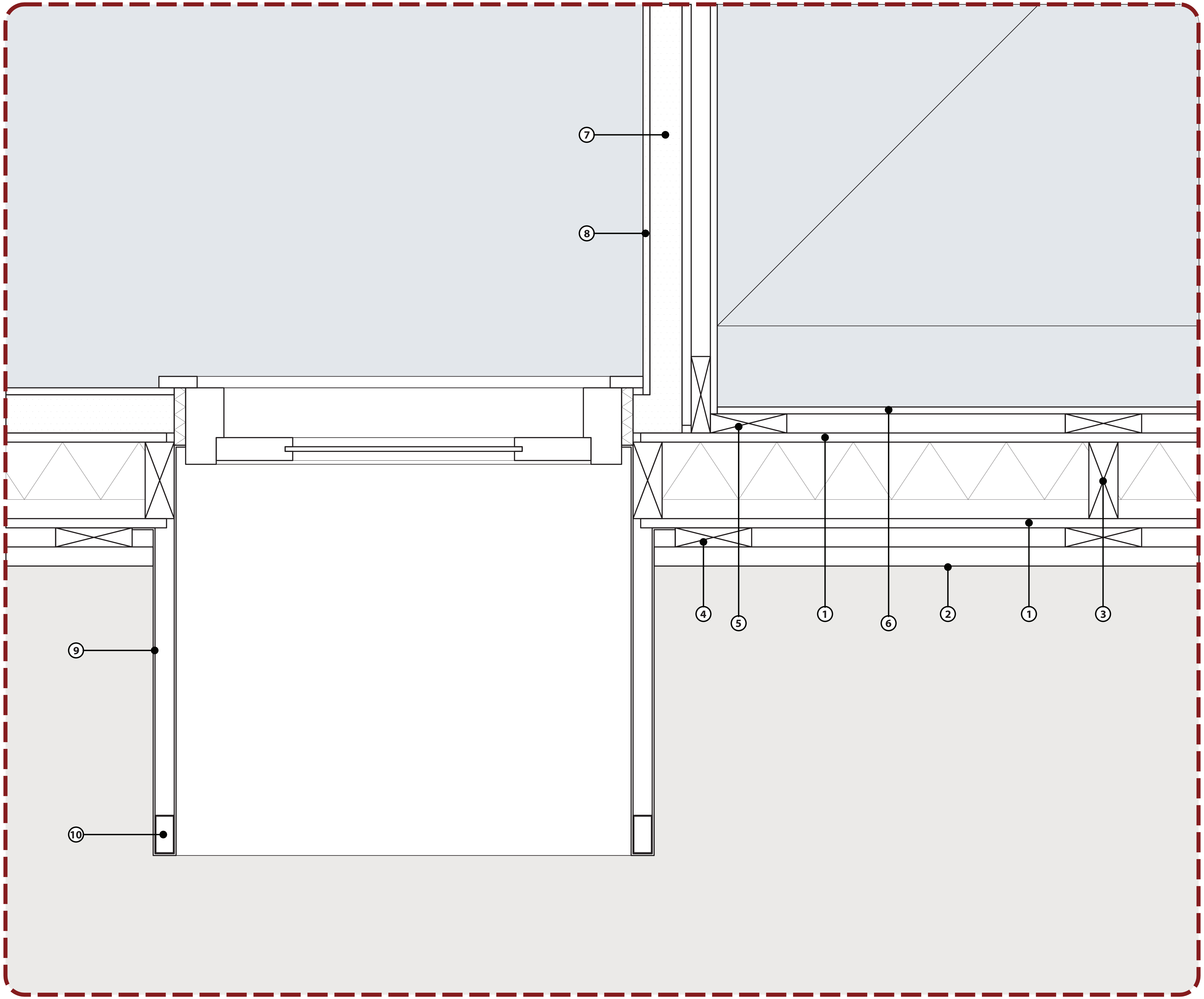


1. CHIPPED BOARD PANEL: 240x120 mm. 12 mm. thickness
2. SAWN WOOD WALL CLADDING: 150x25 mm.
3. SAWN WOOD WALL JOIST: 100x38 mm.
4. SAWN WOOD WALL JOIST: 100x25 mm.
5. GLULAM COLUMN: 140x140 mm.
6. SAWN WOOD : 200x50 mm.
7. SAWN WOOD : 150x50 mm.

Detail 1 **scale 1:5**







1. CHIPPED BOARD PANEL: 240x120 mm. 12 mm. thickness
2. SAWN WOOD WALL CLADDING: 150x25 mm.
3. SAWN WOOD WALL JOIST: 100x38 mm.
4. SAWN WOOD WALL JOIST: 100x25 mm.
5. SAWN WOOD WALL JOIST: 100x25 mm.
6. GYPSUM BOARD PANEL: 240x120 mm. 12 mm. thickness
7. CEMENT FILL: 50 mm. thickness
8. CERAMIC TILE
9. STEEL WINDOW FRAME: 2.5 thickness
10. STEEL BOX FRAME: 50x25 mm.

Detail 2 **scale 1:5**

1 GLULAM BEAM: 315x140 mm.

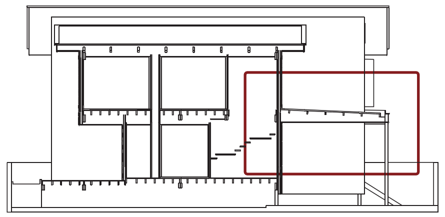
2 GLULAM BEAM: 360x140 mm.

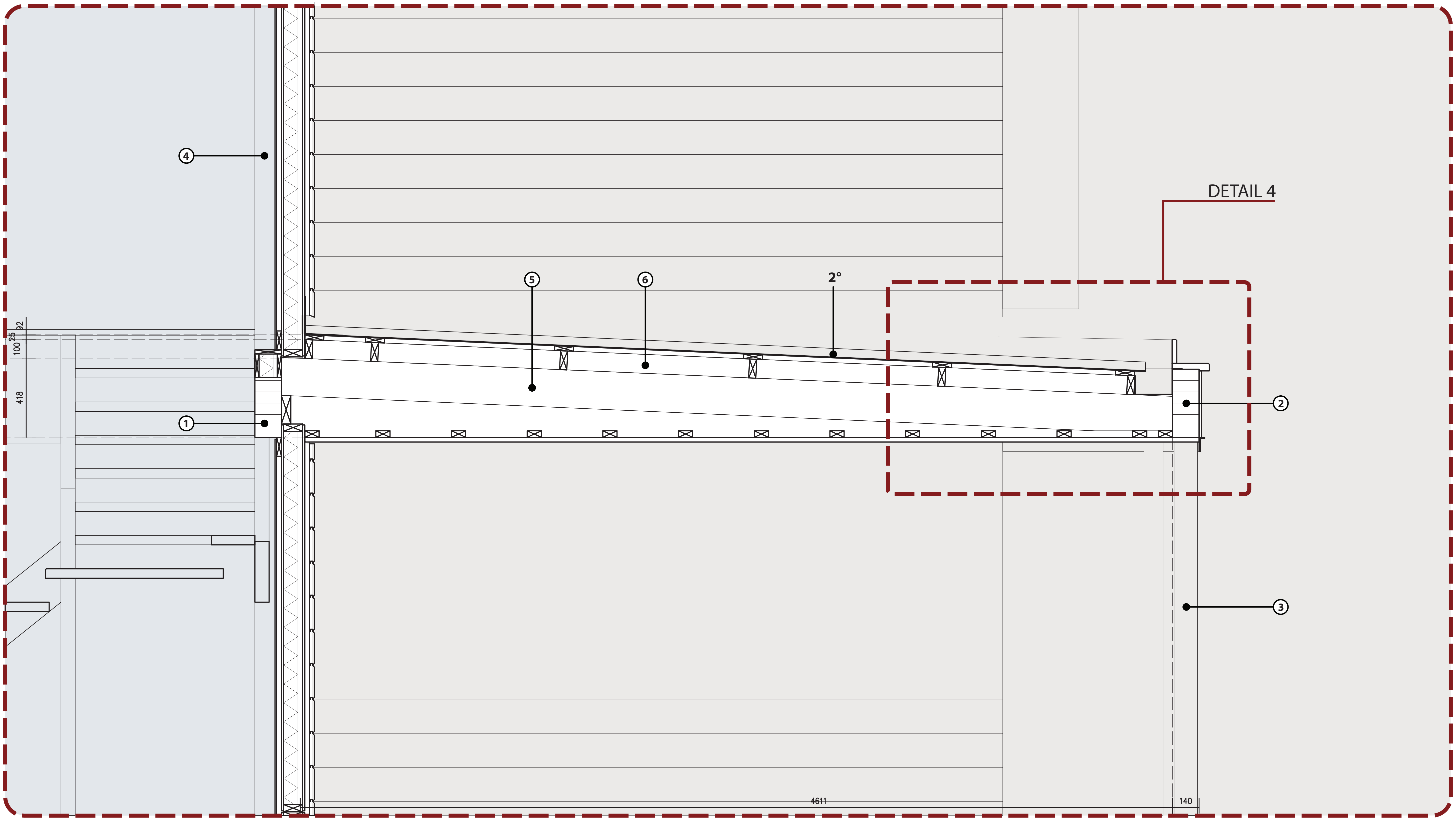
3 H STEEL COLUMN: 360x140 mm.

4 GLULAM COLUMN: 140x140 mm.

5 SAWN WOOD RAFTER: 200x75 mm.

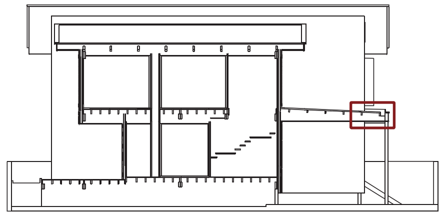
6 SAWN WOOD PURLIN: 200x75 mm.



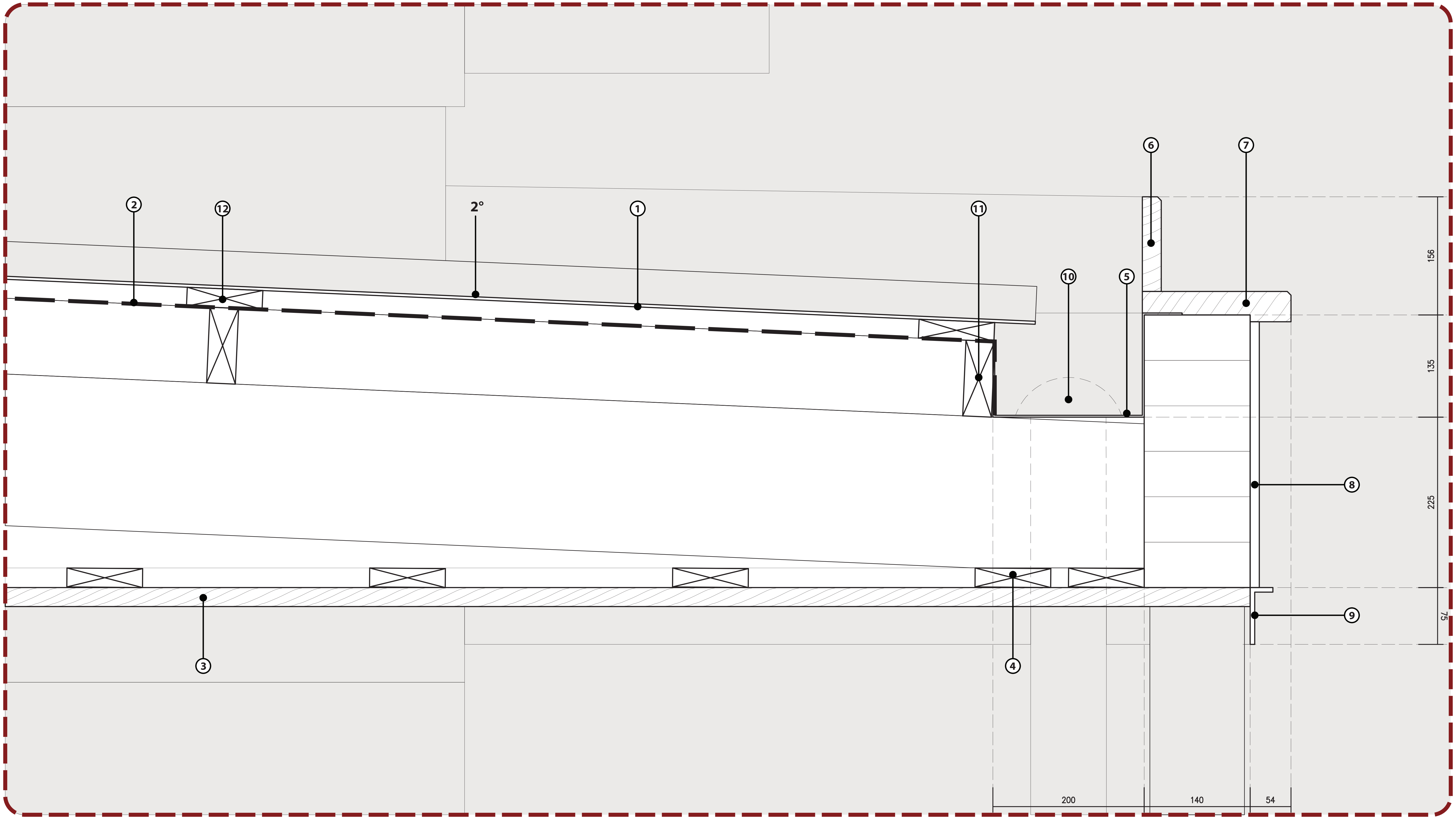


Detail 3

scale 1:20

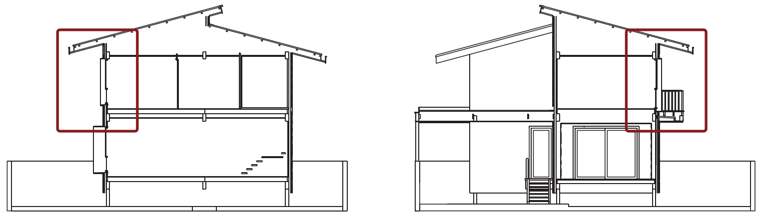


1. METAL SHEET ROOF
2. ROOFING MEMBRANE
3. SAWN WOOD CEILING: 100x25 mm.
4. SAWN WOOD CEILING JOIST: 100x25 mm.
5. STEEL GUTTER: 2.5 mm. thk
6. SAWN WOOD FASCIA: 125x25 mm.
7. SAWN WOOD FASCIA: 200x50 mm.
8. SCEMENT BOARD FASCIA: 12 mm. thk
9. STEEL FASCIA: 2.5 mm. thk
10. ROOF DRAIN
11. PRIMARY PURLINS: 100x38 mm.
12. SECONDARY PURLINS: 100x25 mm.

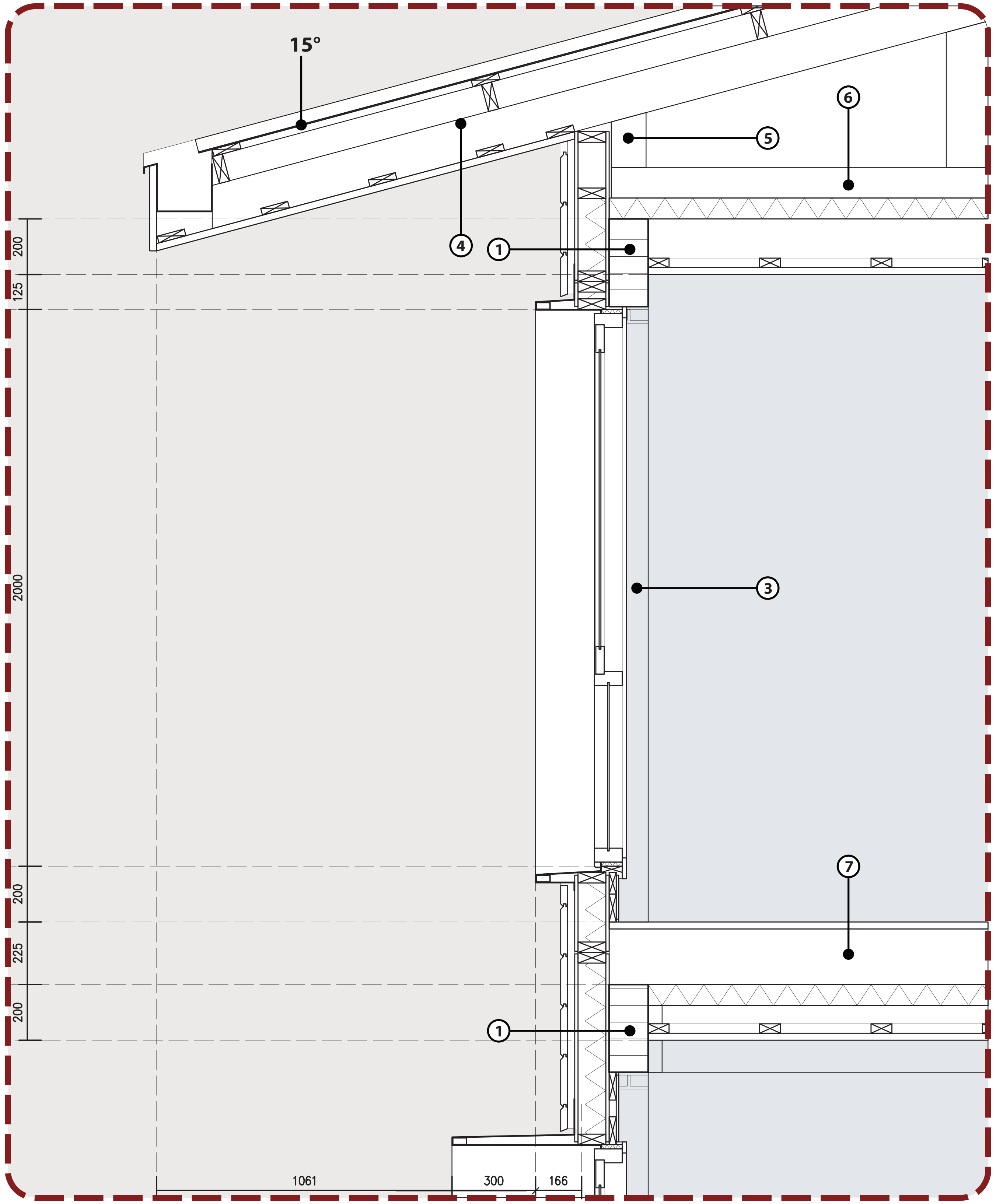


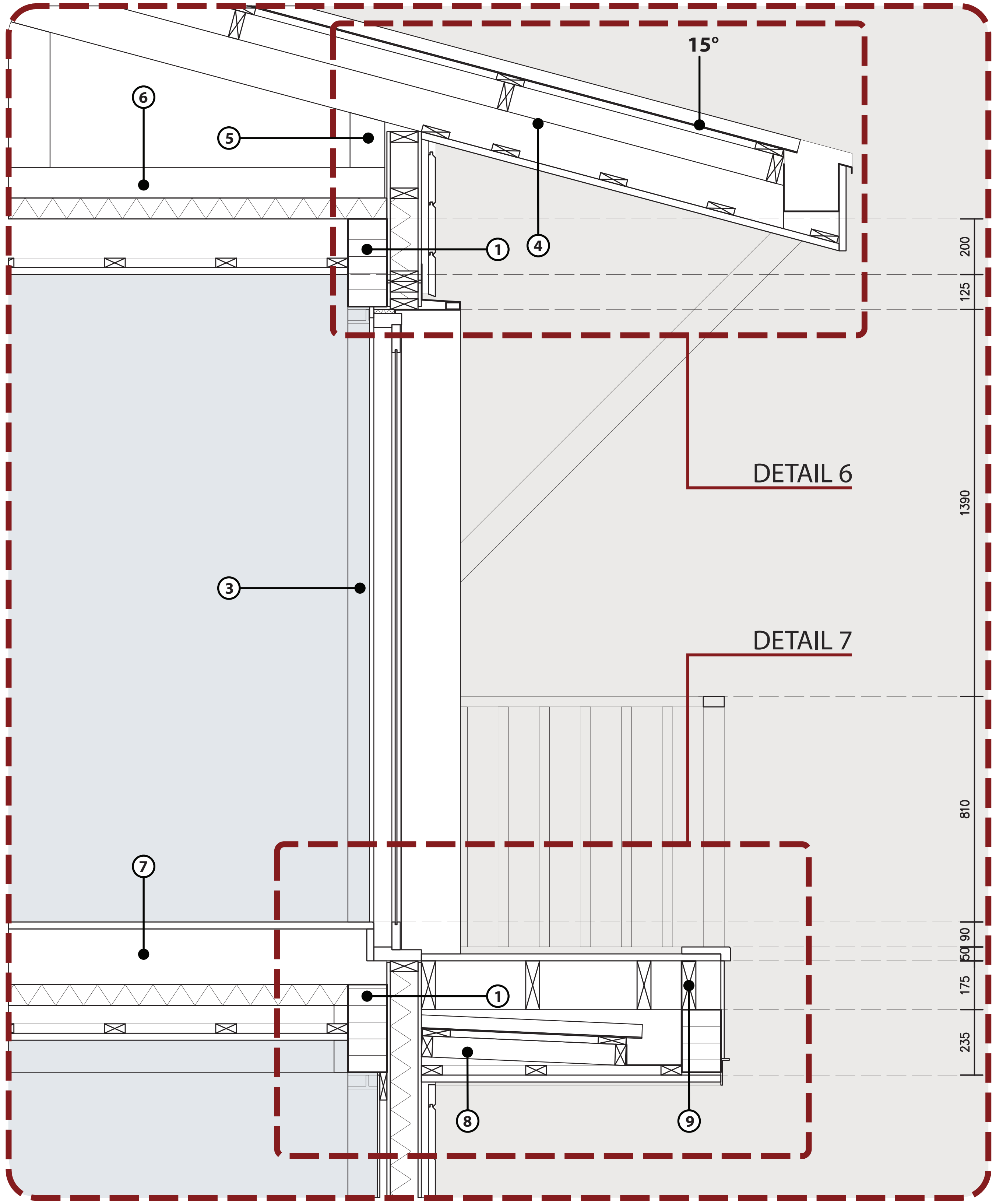
Detail 4

scale 1:5



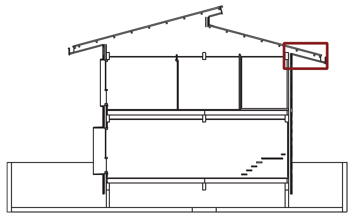
1. GLUALAM BEAM: 315x140 mm.
2. GLUALAM BEAM: 235x140 mm.
3. GLUALAM COLUMN: 140x140 mm.
4. SAWN WOOD RAFTER: 150x50 mm.
5. SAWN WOOD TRUSS: 125x50 mm.
6. SAWN WOOD TRUSS: 175x50 mm.
7. SAWN WOOD FLOOR JOIST: 200x50 mm.
8. SAWN WOOD RAFTER: 75x50 mm.
9. SAWN WOOD FLOOR JOIST: 175x50 mm.



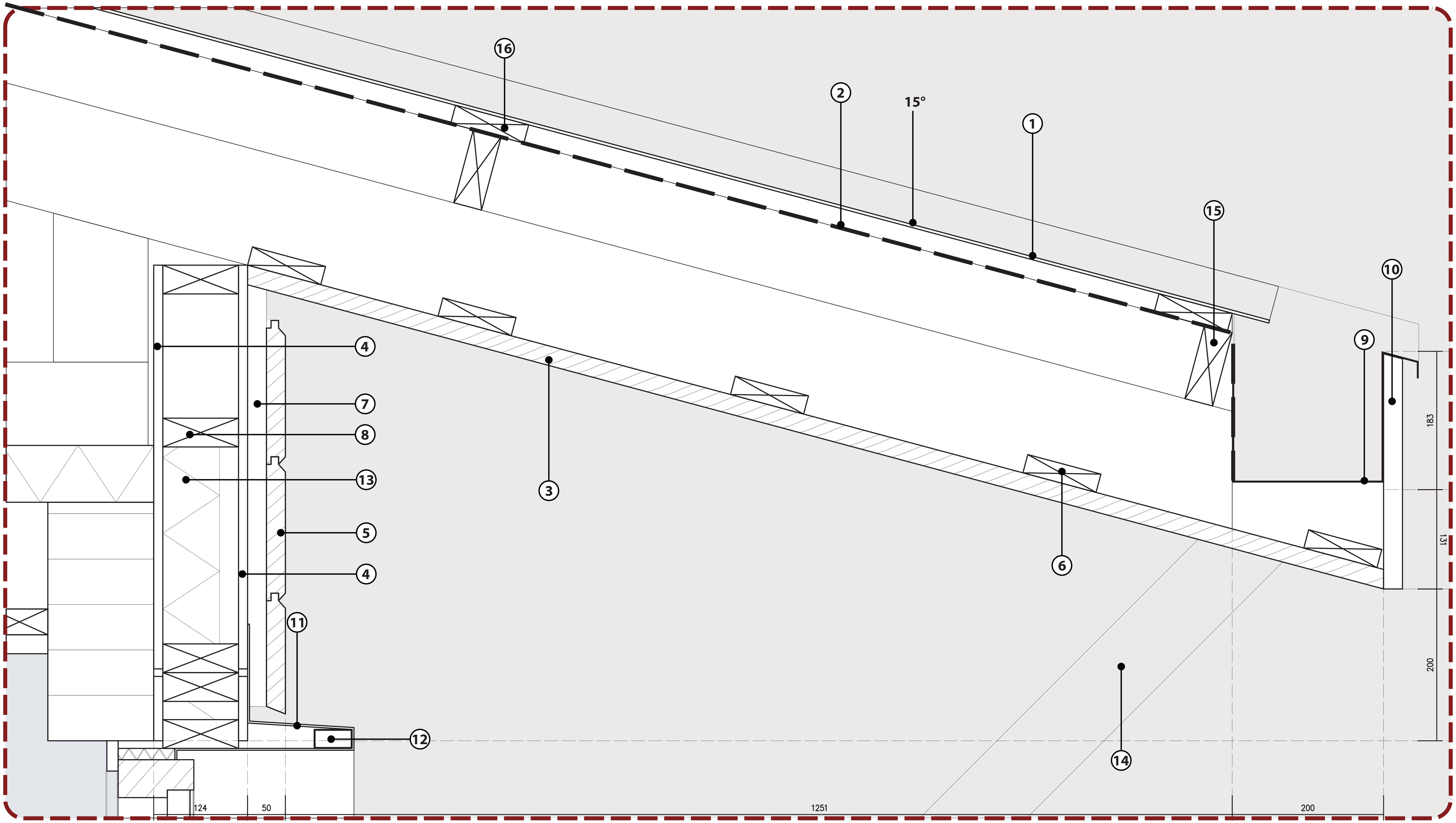


Detail 5

scale 1:20

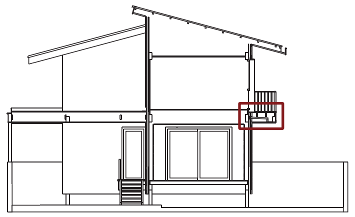


1. METAL SHEET ROOF
2. ROOFING MEMBRANE
3. SAWN WOOD CEILING; 100x25 mm.
4. CHIPPED BOARD PANEL: 240x120 mm.12 mm. thk
5. SAWN WOOD WALL CLADDING: 150x25 mm.
6. SAWN WOOD CEILING JOIST: 100x25 mm.
7. SAWN WOOD WALL JOIST: 100x25 mm.
8. SAWN WOOD WALL JOIST: 100x25 mm.
9. STEEL GUTTER: 2.5 mm. thk
10. CEMENT BOARD FASCIA: 22 mm. thk
11. STEEL WINDOW FRAME: 2.5 mm. thk
12. STEEL BOX FRAME: 50x25 mm.
13. MINERAL WOOL: 75 mm. thk
14. ROOF DRAIN PIPE: 100x100 mm.
15. PRIMARY PURLIN: 100x38 mm.
16. SECONDARY PURLIN: 100x25 mm.

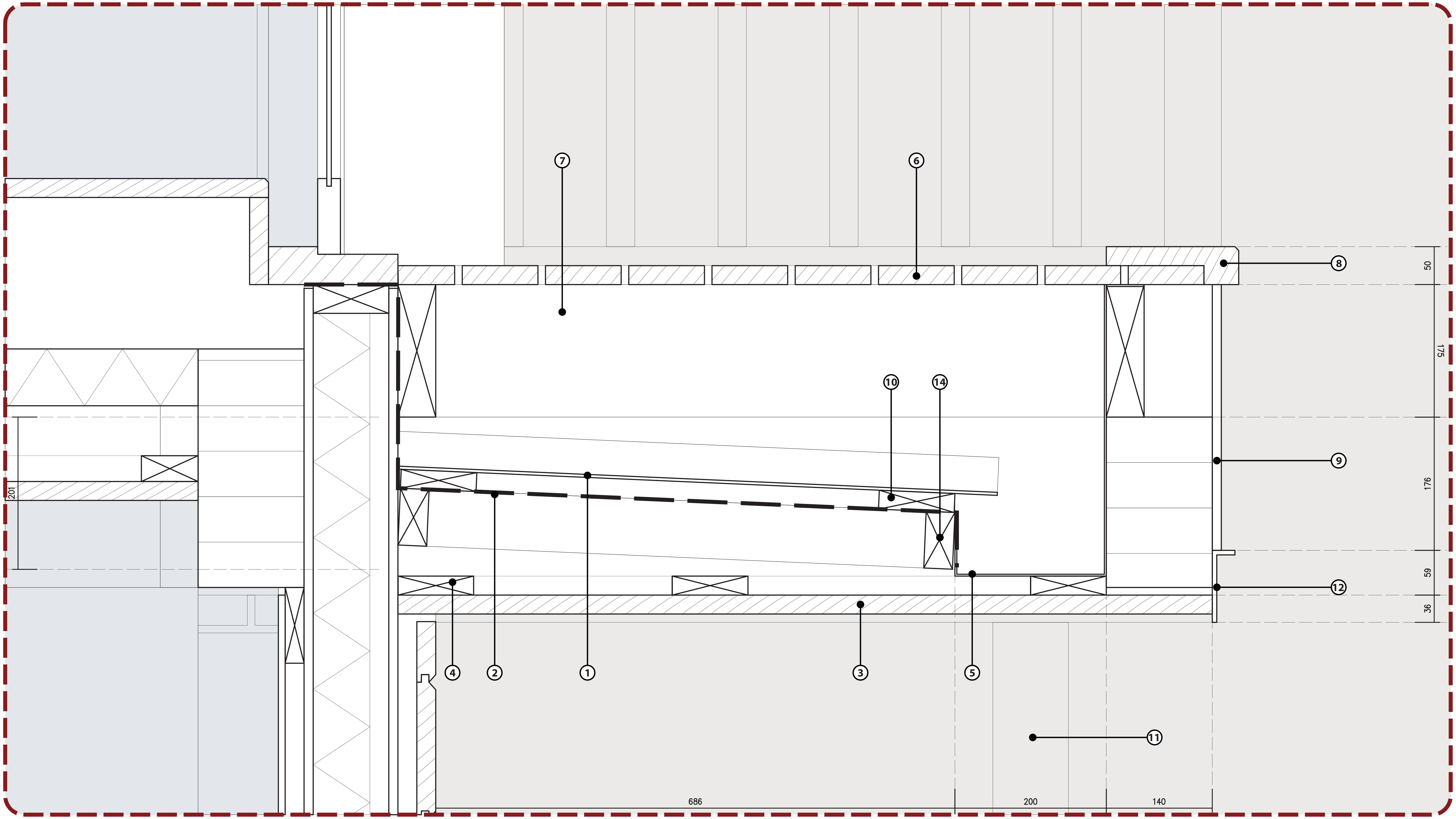


Detail 6

scale 1:5

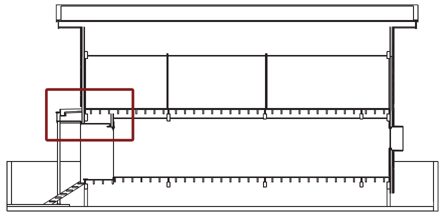


1. METAL SHEET ROOF
2. ROOFING MEMBRANE
3. SAWN WOOD CEILING: 100x25 mm.
4. SAWN WOOD CEILING JOIST: 100x25 mm.
5. STEEL GUTTER: 2.5 mm. thk
6. SAWN WOOD FLOOR: 100x25 mm.
7. SAWN WOOD FLOOR JOIST: 175x50 mm.
8. SAWN WOOD FASCIA: 175x50 mm.
9. CEMENT BOARD FASCIA: 12 mm. thk
10. PRIMARY PURLIN:100x25 mm.
11. ROOF DRAIN PIPE: 100x100 mm.
12. STEEL FASCIA: 2.5 mm. thk
13. SECONDARYP PURLIN: 100x34 mm.

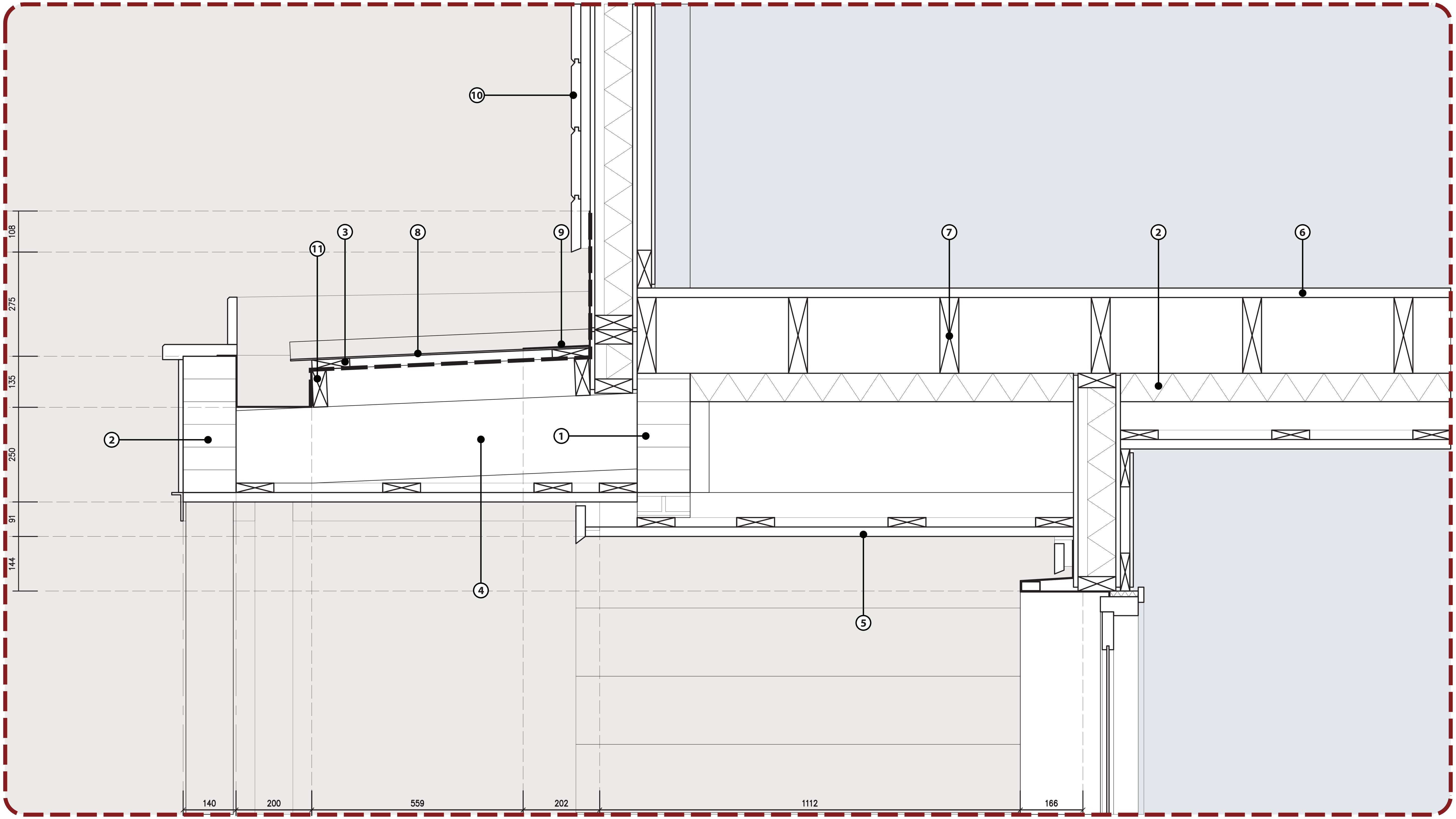


Detail 7

scale 1:5

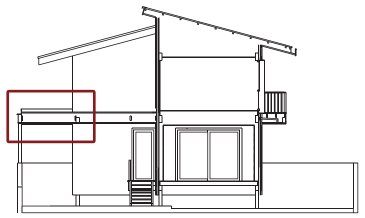


1. GLULAM BEAM: 315x140 mm.
2. GLULAM BEAM: 360x140 mm.
3. SECONDARY PURLIN: 100x25 mm.
4. SAWN WOOD RAFTER: 200x75 mm.
5. SAWN WOOD CEILING: 100x25 mm.
6. SAWN WOOD FLOOR: 100x25 mm.
7. SAWN WOOD FLOOR JOIST: 175x50 mm.
8. METAL SHEET ROOF
9. STEEL FLASHING: 2.5 mm. thickness
10. SAWN WOOD WALL CLADDING: 150x25 mm.
11. PRIMARY PURLIN: 100x34 mm.

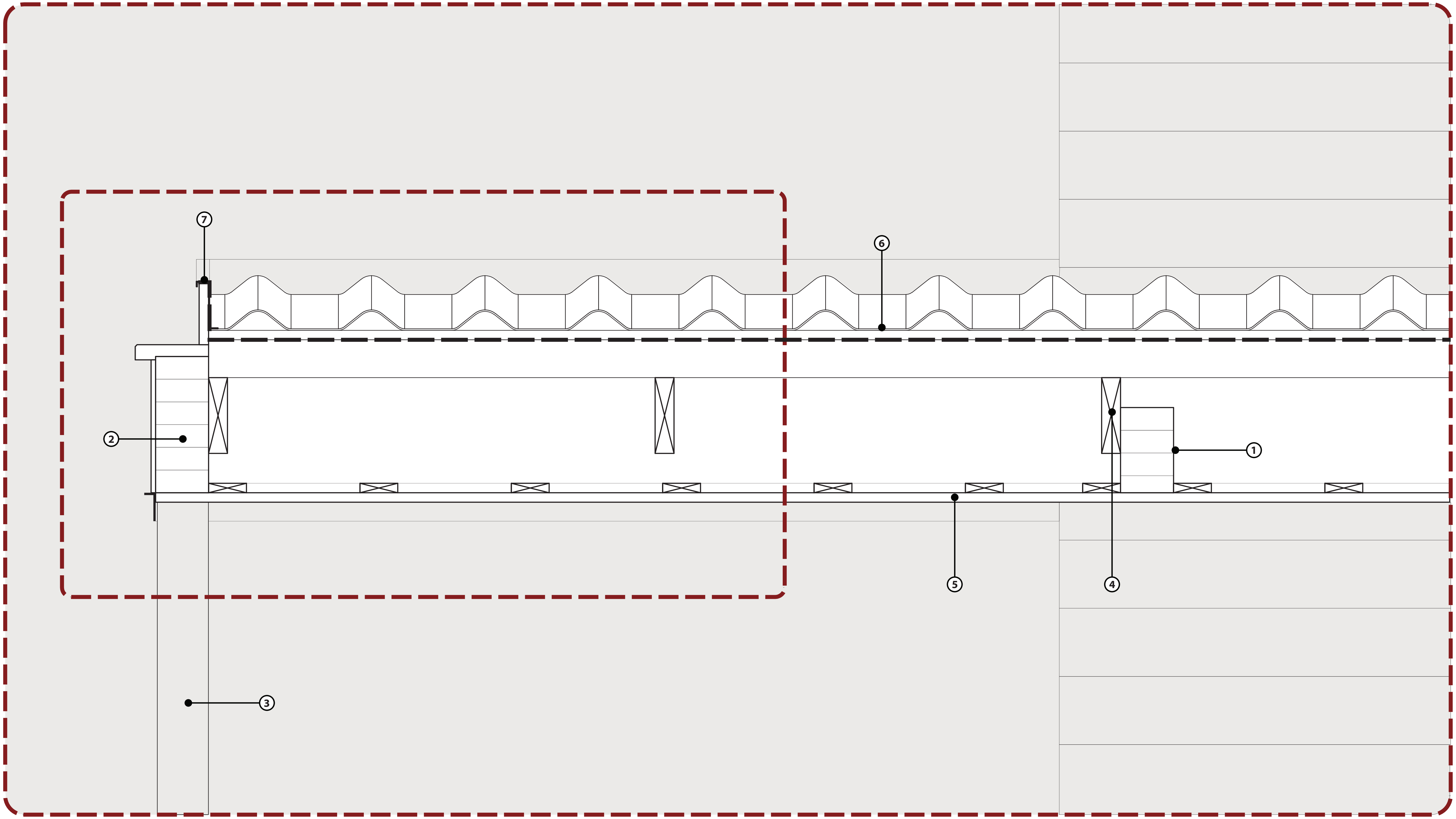


Detail 8

scale 1:10

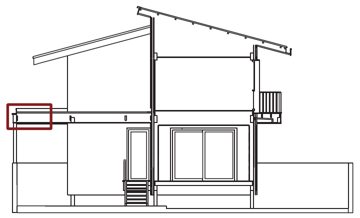


1. GLULAM BEAM: 315x140 mm.
2. GLULAM BEAM: 360x140 mm.
3. GLULAM COLUMN: 140x140 mm.
4. SAWN WOOD RAFTER: 200x75 mm.
5. SAWN WOOD CEILING: 100x25 mm.
6. METAL SHEET ROOF
7. STEEL FLASHING: 2.5 thk



Detail 9

scale 1:10



1 METAL SHEET ROOF

2 ROOFING MEMBRANE

3 SAWN WOOD CEILING: 100x25 mm.

4 SAWN WOOD CEILING JOIST: 100x25 mm.

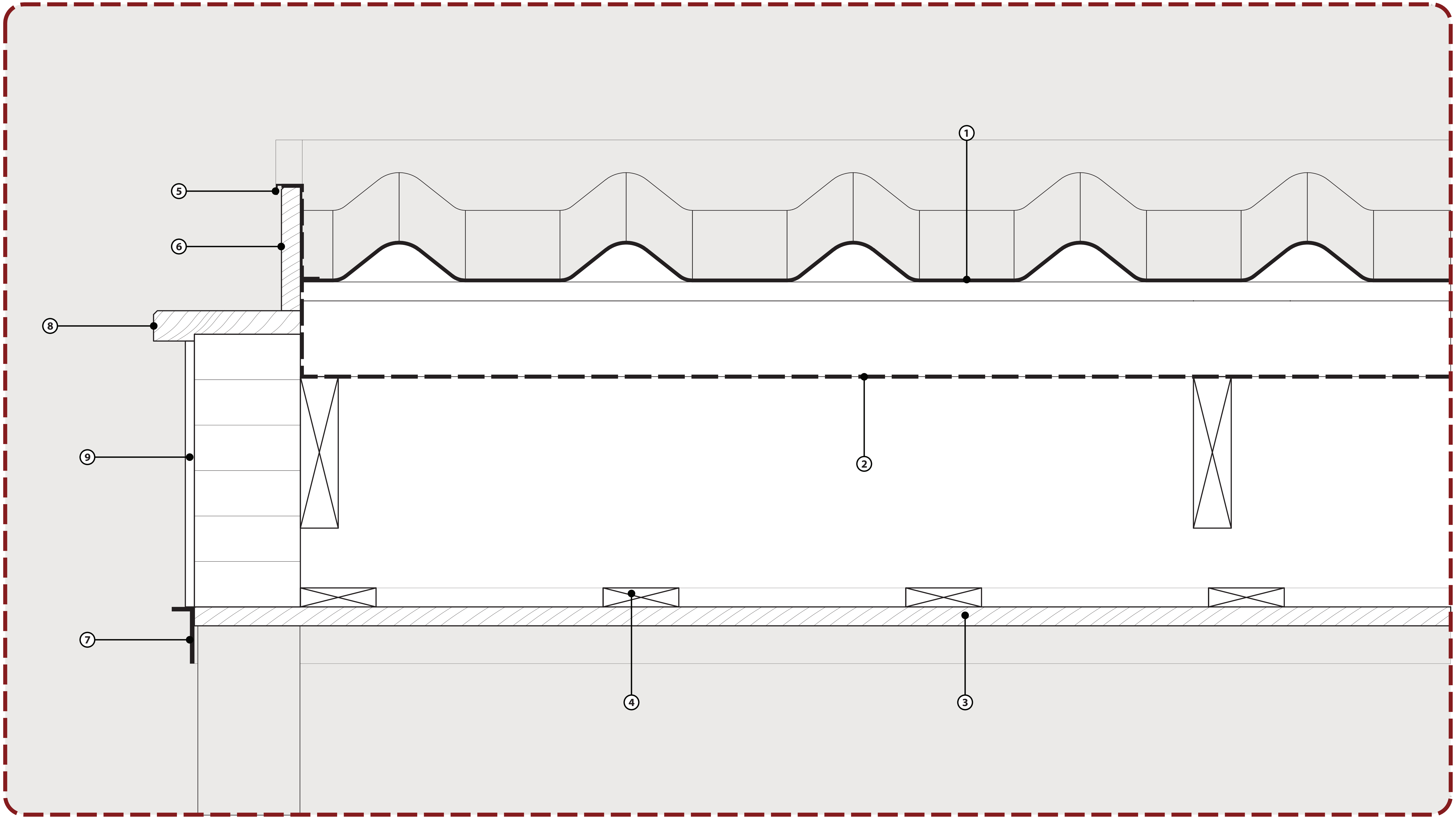
5 STEEL FLASHING: 2.5 mm. thk

6 SAWN WOOD FASCIA: 125x25 mm.

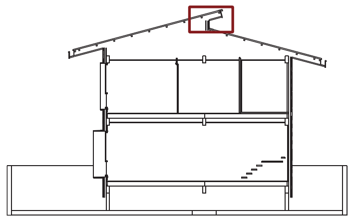
7 STEEL FASCIA: 2.5 mm. thk

8 SAWN WOOD FASCIA: 175x50 mm.

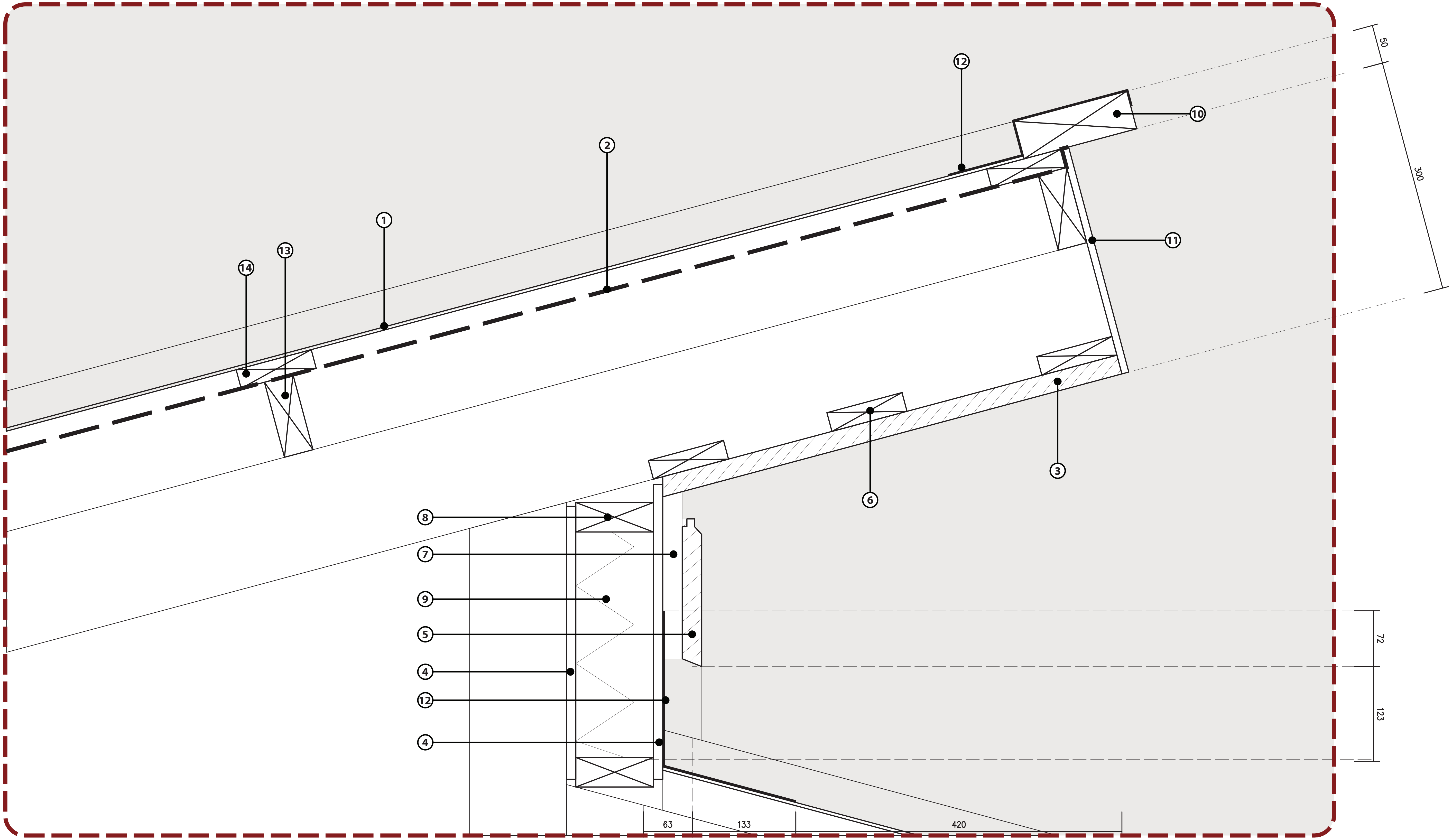
9 CEMENT BOARD FASCIA: 12 mm. thk



Detail 10 scale 1:10

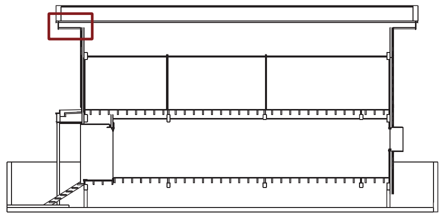


1. METAL SHEET ROOF
2. ROOFING MEMBRANE
3. SAWN WOOD CEILING: 100x25 mm.
4. CHIPPED BOARD PANEL: 240x120 mm.12 mm. thk
5. SAWN WOOD WALL CLADDING: 150x25 mm.
6. SAWN WOOD CEILING JOIST: 100x25 mm.
7. SAWN WOOD WALL JOIST: 100x25 mm.
8. SAWN WOOD WALL JOIST: 100x38 mm.
9. MINERAL WOOL: 75 mm. thk
10. SAWN WOOD FASCIA: 150x50 mm.
11. CEMENT BOARD FASCIA: 8 mm. thk
12. STEEL FLASHING: 2.5 mm. thk
13. PRIMARY PURLIN: 100x38 mm.
14. SECONDARY PURLIN: 100x25 mm.

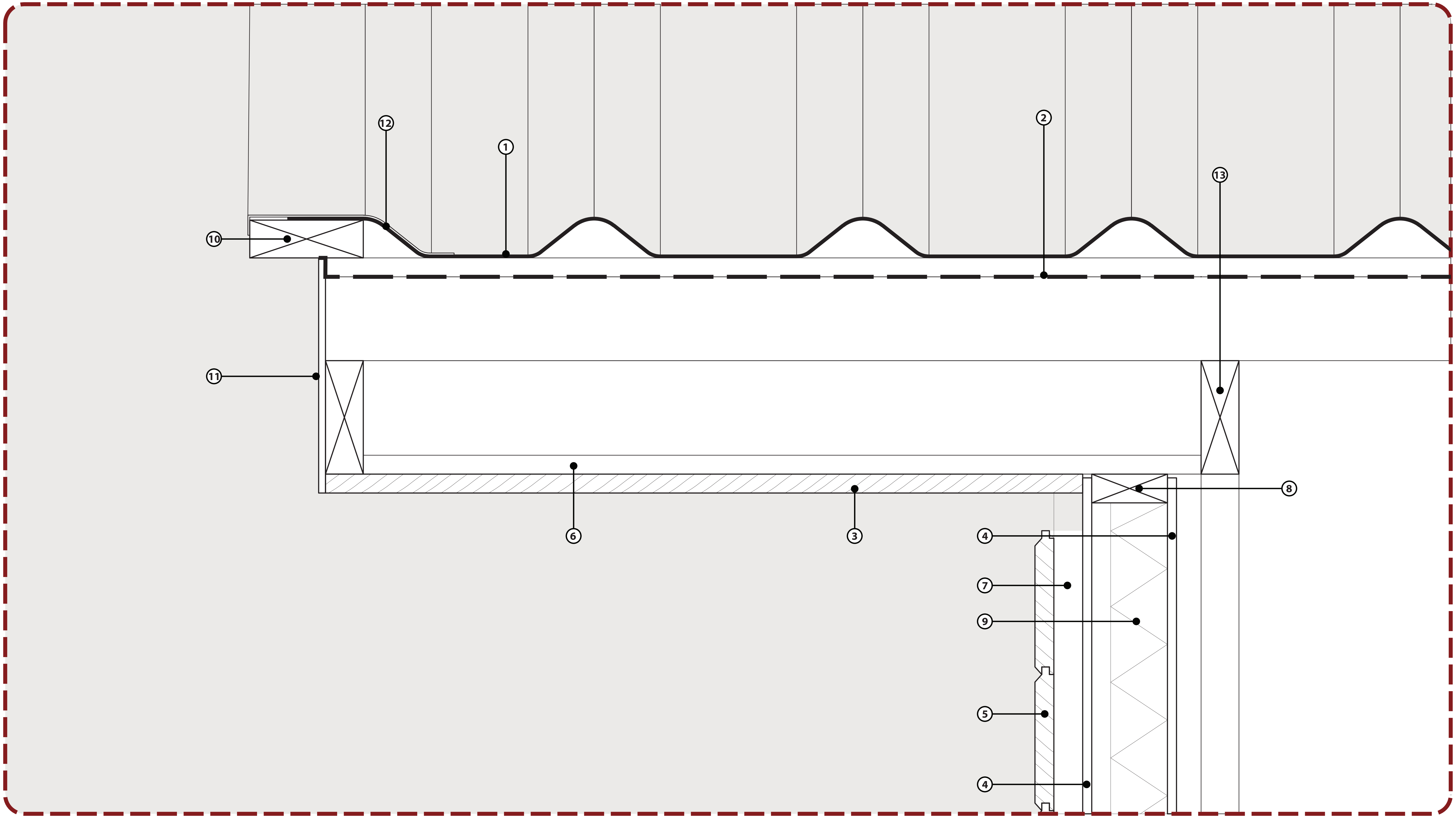


Detail 11

scale 1:10



1. METAL SHEET ROOF
2. ROOFING MEMBRANE
3. SAWN WOOD CEILING: 100x25 mm.
4. CHIPPED BOARD PANEL: 240x120 mm. 12 mm. thk
5. SAWN WOOD WALL CLADDING: 150x25 mm.
6. SAWN WOOD CEILING JOIST: 100x25 mm.
7. SAWN WOOD WALL JOIST: 100x25 mm.
8. SAWN WOOD WALL JOIST: 150x25 mm.
9. MINERAL WOOL: 75 mm. thk
10. SAWN WOOD FASCIA: 150x50 mm.
11. CEMENT BOARD FASCIA: 8 mm. thk
12. STEEL FLASHING: 2.5 mm. thk
13. SAWN WOOD RAFTER: 150x50 mm.



Detail 12

scale 1:10

fig 84. Thai Local Timber - source: Viriyaroj B.

VIII. Evaluation

Basis of evaluation

The evaluation process aims to calculate the performance of the prototype buildings in comparison to conventional concrete buildings in Thailand. Throughout the development process of this project, the method to achieve this goal has been focusing on familiarization of contemporary timber construction. This decision put the project in to the environment which it has to compete with other more widespread and developed solution. There will be two matrixes of evaluation for "Thai contemporary timber construction system". They are construction cost and CO_2 emission.

Material cost is one of, if not, the largest obstacle for the development of contemporary timber construction in Thailand. With the intervention of new source of material and construction knowledge, the cost of construction built by "Thai contemporary timber construction system" should be evaluated to determine its potential. This project has the opportunity to determine this potential by evaluating the price of timber construction and concrete construction on equal ground. This process can be done by using the same house design but with different materials and construction system. The material of one of the prototype timber houses will be replace with conventional construction then the price can be compared.

As for CO_2 emission, the core motivation of this project is addressing the problem of climate change through low carbon timber construction. This core motivation makes the evaluation of carbon emission detrimental to the development of this thesis. Furthermore, environmental awareness is currently gaining significant awareness by the Thais, especially in younger generations. Therefore, the different between the CO_2 emission of conventional construction and timber construction can definitely be used as promotional tools by "Thai contemporary timber construction system" and making it more appealing to this emerging market.

Framework

Establishing the framework of evaluation is the next important step before the process of evaluation can proceed. This process is detrimental for creating a relevant result of evaluation. The framework will be created by determining which information is needed to achieve a meaningful data. In the scope of this thesis, not all phases in life cycle assessment (LCA) can be realistically included. Construction material is the main focus of this thesis. Therefore, the phases which have no information related to material production will be excluded. These phases are construction phase, energy consumption during usage phase and end of life phase. However, material replacement in the usage phase is still included in the evaluation, since it deals with the production of building components. Even though the usage phase is currently the most relevant phase in LCA, especially in the context of comparing timber construction with concrete construction, it is outside of the scope of this thesis. More importantly, the calculation of energy consumption in buildings need many resources which are not available to this project to create a reliable data. From these reasons the LCA phases which will be included in the framework are; production phase including transportation and material replacement in usage phase.

Another important aspect in this framework is determining the items that will to be included in the calculation. In normal LCA cases, precision of the calaculation will be increase with more items included, because it will bring the outcome closer to the actual number in built projects. However, the evaluation process in this thesis has high degree of comparative nature. Aiming for precise number of CO_2 emission and construction cost is not the goal, but rather, the competitiveness of the design in comparison to conventional construction. This leave room for the process to be streamline by excluding every building component which are shared between conventional concrete construction and "Thai contemporary timber construction system". This means that, every material besides architectural elements and structural elements will be excluded from this evaluation. This exclusion also applies to all of the chemical based elements; i.e. paints and sealants, because they can be equally applied in both construction type. Some of the small assembling components will also be removed. This include nails and bolts in timber construction, welding rod in steel construction and concrete formwork in concrete construction.

All in all, this evaluation is designed to create a rough comparative estimation between two construction systems. Since, this evaluation process aims for a rough estimation, the numbers of cost and CO_2 emission per units will come from average values. The evaluation will be more favorable towards concrete construction because the goal is to explore the potential of timber houses. This is done for the purpose of avoiding overly optimistic result.

fig 85. Production Phase

fig 86. Transportation in Production Phase

fig 87. Material Replacement in Usage Phase

fig 85. Production Phase - source : http://hawkinssawmill.com/north-central-mn-sawmill-about-hawkins-sawmill/
fig 86. Transportation in Production Phase - source : http://www.timbeter.com/timber-trucks-transportation-companies/
fig 87. Material Replacement in Usage Phase - source : https://www.euractiv.com/section/climate-environment/news/half-of-french-climate-finance-spent-on-building-renovation/

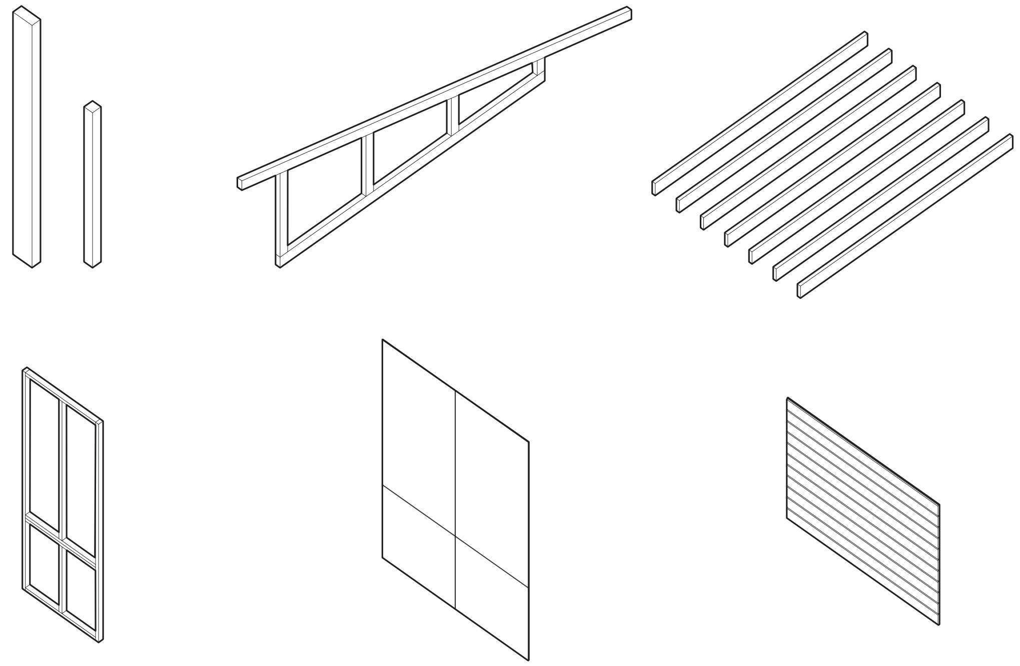
Materials

The possibility of alternative material is a topic that should also be evaluate, besides the two main construction material; European pine wood and conventional construction materials. Even though, it has been established through numerous reasons that European pine wood is possibly the most suitable material for this project, the result of calculation might still be unpredictable. Timber construction using local wood and steel construction has been previously mentioned and are the construction type that should also be included in the claculation. Several species of local timber have been known to withstand the tropical climate as well as the threat of termite. Shorea obtusa is one of the species that is often used as structural timber in Thailand and is one of the cheaper wood species. In addition, it lacks the negative impact of material shipping from overseas sources. As for steel construction, the advantage it has come from its establishment within Thai construction industry. Steel is a common construction material in Thailand and there are plenty of knowledge and workers attached to this construction type. These two construction types might have potential to perform well in some calculatiob as alternative materials for "Thai contemporary timber construction system". Therefore, they will be included in the evaluation of material cost and CO_2 emission.

fig 88. Scots pine (Pinus sylvestris)

fig 89. Shorea obtusa

fig 88. Scots pine (Pinus sylvestris) - photo : Viriyaroj B.
fig 89. Shorea obtusa - source : https://commons.wikimedia.org/wiki/Pinus_sylvestris



With the introduction of different construction materials in to the evaluation process, the possibility of optimization through combination of elements from different material system is an interesting proposition. The optimization through combination of different system might yield the outcome that can balance between construction cost and CO_2 emission. In another word, a compromised solution. In order to execute this process of optimization, without creating an overburden task, a system must be established to facilitate the process. From this reason, each construction system will be divided in to groups of building elements in the calculation. The grouping of construction elements will be as following.

1. Primary structural elements - This group include all the primary structure. The joints components for primary structure belong to this group. Concrete floor also has to be included as well, since it is a continuation of concrete beams, a primary structure.

2. In fill elements – In fill elements has all the building components which are not primary structure or finishing elements in this group. Studs, non-finishing panels, membrane, insulation and secondary structure in roofing elements belong to this group.

3. Finishing elements - The group consists of all the finishing elements of the whole building. Standalone elements such as, doors, windows, stairs and railings are also included.

The evaluation of these alternative elements and combination will go through the same comparative concept, similar to timber construction with imported wood.

House type

There is little to be gained from evaluating all of the building prototypes, since this process has the purpose of creating a rough comparative estimation between two construction systems. This means that, a house type, among the three prototype houses, has to be chosen. The rule of maximizing number of audiences still applied here. Therefore, commercial houses will be chosen because of its larger potential impact. Between single detach house and row house, the former is a more common house type in Thailand. As a result, commercial single detach house is the chosen building type for the process of evaluation.

Calculation results

Total building area = 223.00	System 1 (imported timber construction)				System 2 (local timber construction)			
Cost and Emissions	Phase 1		Phase 1 + Replacement		Phase 1		Phase 1 + Replacement	
Primary structure								
total cost ฿	359,727.00	฿	359,727.00	฿	396,201.09	฿	396,201.09	฿
total cost €	10,133.16	€	10,133.16	€	11,160.59	€	11,160.59	€
total emission	16,144.36	kg.	16,144.36	kg.	12,867.00	kg.	12,867.00	kg.
Secondary Structure (infill)								
total cost ฿	444,997.12	฿	543,976.62	฿	574,651.33	฿	659,595.35	฿
total cost €	12,535.13	€	15,323.29	€	16,187.36	€	18,580.15	€
total emission	9,451.08	kg.	10,787.35	kg.	7,809.18	kg.	8,770.41	kg.
Finishing								
total cost ฿	518,277.34	฿	706,285.31	฿	621,448.47	฿	993,226.81	฿
total cost €	14,599.36	€	19,895.36	€	17,505.59	€	27,978.22	€
total emission	15,942.95	kg.	22,727.43	kg.	13,281.59	kg.	17,754.72	kg.
Summary								
total cost ฿	1,323,001.47	฿	1,609,988.93	฿	1,592,300.89	฿	2,049,023.25	฿
total cost €	37,267.65	€	45,351.80	€	44,853.55	€	57,718.96	€
total emission	41,538.38	kg.	49,659.14	kg.	33,957.76	kg.	39,392.13	kg.
total emission (with carbon storage)	-834.93	kg.	-4344.00	kg.	33,957.76	kg.	39,392.13	kg.
cost/area ฿	5,932.74	฿	7,219.68	฿	7,140.36	฿	9,188.45	฿
cost/area €	167.12	€	203.37	€	201.14	€	258.83	€
emission/area	186.27	kg.	222.69	kg.	152.28	kg.	176.65	kg.
emission/area (with carbon storage)	-3.74	kg.	-19.48	kg.	152.28	kg.	176.65	kg.
Comparison with conventional construction								
cost %	129.98	%	138.90	%	156.44	%	176.77	%
emission %	53.82	%	59.46	%	44.00	%	47.17	%
emission% (with carbon storage)	-1.08	%	-5.20	%	44.00	kg.	47.17	%

Total building area = 223.00	System 3 (steel construction)				System 4 (conventional construction)			
Cost and Emissions	Phase 1		Phase 1 + Replacement		Phase 1		Phase 1 + Replacement	
Primary structure								
total cost ฿	380,862.27	฿	380,862.27	฿	386,994.74	฿	386,994.74	฿
total cost €	10,728.51	€	10,728.51	€	10,901.26	€	10,901.26	€
total emission	38,187.54	kg.	38,187.54	kg.	40,224.97	kg.	40,224.97	kg.
Secondary Structure (infill)								
total cost ฿	353,282.95	฿	353,282.95	฿	309,851.45	฿	309,851.45	฿
total cost €	9,951.63	€	9,951.63	€	8,728.21	€	8,728.21	€
total emission	18,939.32	kg.	18,939.32	kg.	21,635.70	kg.	21,635.70	kg.
Finishing								
total cost ฿	461,218.36	฿	665,830.10	฿	320,997.86	฿	462,287.60	฿
total cost €	12,992.07	€	18,755.78	€	9,042.19	€	13,022.19	€
total emission	16,980.61	kg.	24,663.61	kg.	15,324.20	kg.	21,653.25	kg.
Summary								
total cost ฿	1,195,363.59	฿	1,399,975.33	฿	1,017,844.06	฿	1,159,133.79	฿
total cost €	33,672.21	€	39,435.92	€	28,671.66	€	32,651.66	€
total emission	74,107.47	kg.	81,790.47	kg.	77,184.87	kg.	83,513.91	kg.
total emission (with carbon storage)	74,107.47	kg.	81,790.47	kg.	77,184.87	kg.	83,513.91	kg.
cost/area ฿	5,360.37	฿	6,277.92	฿	4,564.32	฿	5,197.91	฿
cost/area €	151.00	€	176.84	€	128.57	€	146.42	€
emission/area	332.32	kg.	366.77	kg.	346.12	kg.	374.50	kg.
emission/area (with carbon storage)	332.32	kg.	366.77	kg.	346.12	kg.	374.50	kg.
Comparison with conventional constructi								
cost %	117.44	%	120.78	%	N/A	%	N/A	%
emission %	96.01	%	97.94	%	N/A	%	N/A	%
emission% (with carbon storage)	96.01	%	97.94	%	N/A	%	N/A	%

data from: Prof. Geo7 Hammond & Craig Jones. (2011) Inventory of Carbon & Energy (ICE) Version 2.0

Calculation results

Imported timber - Construction cost = 138,90% of concrete construction
- CO_2 emission (without carbon sequestration) = 59,46% of concrete construction
- CO_2 emission (with carbon sequestration) = -5,20% of concrete construction

Local timber
- Construction cost = 176,77% of concrete construction
- CO_2 emission (without carbon sequestration) = 47,17% of concrete construction
- CO_2 emission (with carbon sequestration) = 47,17% of concrete construction

Steel
- Construction cost = 120,78% of concrete construction
- CO_2 emission (without carbon sequestration) = 97,94% of concrete construction
- CO_2 emission (with carbon sequestration) = 97,94% of concrete construction

From these results, it can be seen that steel structure perform the best in term of construction cost, while local timber construction performs the best in terms of CO_2 emission. In the subject of carbon emission, steel construction and concrete construction has marginal differences. The price of the house with local timber is hardly competing with conventional construction, where it requires 75% more expense for structural and architectural elements than concrete house.

Imported timber has the middling results for both construction costs and carbon emission. However, if carbon sequestration from sustainable timber sources is taken in to account, imported timber construction become the least carbon emitted of all construction systems. This make using imported timber the most preferable choice if low carbon building is the design goal. This material choice also has advantage over local timber due to its construction cost. The cost of architectural and structural elements for imported timber is roughly 39% more than concrete construction, which is considerably higher. Nonetheless, if end of life value of timber is factoring in with the construction cost, imported wood construction can be very competitive with concrete house. The end of life opportunity for timber is the aspect that has been part of timber construction in Thailand. Due to the rarity of good quality timber, disassembled construction grade woods that still retain their quality are guaranteed to be bought and reintroduce to construction cycle.

Even though, imported wood already has satisfactory performance for both CO_2 emission and price, further optimization can be done to make its price more appealing for Thai users. Looking at the number of each building element in imported timber construction, infill element have the most potential for cost reduction. Comparing to steel construction, a lower price option, infill element for imported wood building is 50% more expensive than steel building. For carbon emission, infill element contributes to the least amount of CO_2, which is around 23% of total emission in steel building. Therefore, cost-optimized construction will be created by replacing the infill element of imported timber building with the one from steel building. The calculation of this "Cost-optimized construction" resulted in the following numbers.

Cost-optimized construction
- Construction cost = 122,40% of concrete construction
- CO_2 emission (without carbon sequestration) = 69,22% of concrete construction
- CO_2 emission (with carbon sequestration) = 34,38% of concrete construction

"Cost optimized construction" has its price almost identical to steel construction but significantly less CO_2 emission. However, it has considerably higher CO_2 emission than imported wood option and no longer has the potential to be a zero-carbon house. All in all, the cost-optimized construction seems to be the most realistic option in the situation where house price is much more valued than environmental impacts.

Cost-optimized construction		
Summary	Summary/area	Comparison with conventional construction
1,419,295.26 ฿	6,364.55 ฿	122,44 ฿
39,435.92 €	176.84 €	122,44 €
57,811.11 kg.	259.24 kg.	69,22 kg.
28,710.89 kg.	128.75 kg.	34,38 kg.

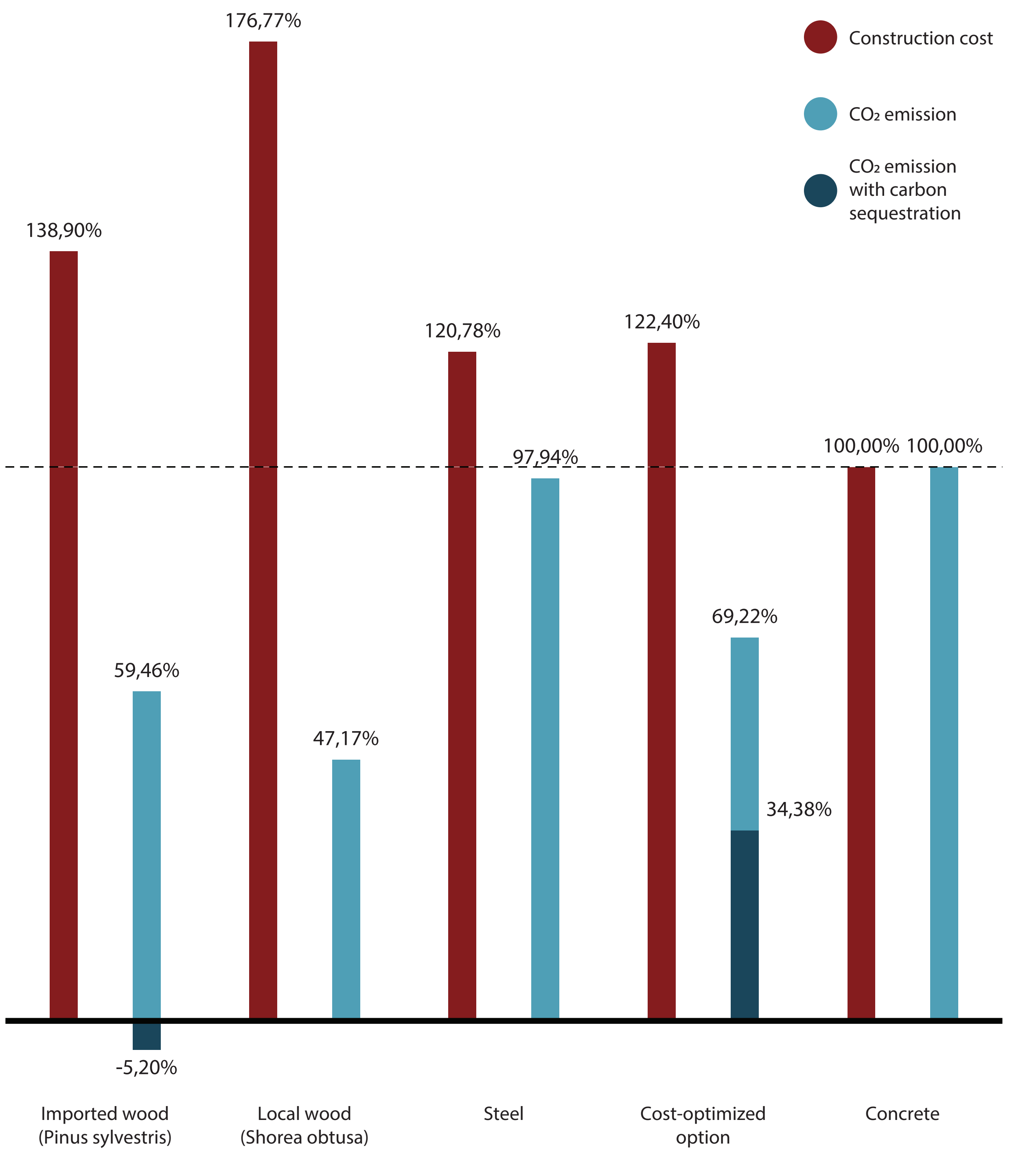


fig 90. Thai Local Timber - photo : Viriyaroj B.

IX. Conclusion

fig 91. Land in Thailand - photo : Viriyaroj B.

Perspective

The culture shift toward a more sustainable construction industry in Thailand is the overarching goal of this project. Even though, the environmental awareness is on the rise in Thailand, it is still in its early stage without any strong established policy to advance sustainable developments. Moreover, this awareness mainly focusses on the daily consumption topic such as plastic, pollution and fossil fuel, but it has not yet reached Thai construction industry. In the current situation, this shift from concrete construction to timber construction will require a holistic approach to many key elements in the industry and in many different levels, which cannot simply be achieved with a single or a handful projects. However, ideal situation is not the approach that this thesis aims for. This project aims to be an early step toward the shift to Thai sustainable construction industry.

This approach can be clearly seen from the decisions that has been taken in the development process of "Thai contemporary timber construction system". This development focus on facilitation and optimization, by the utilization of existing local resources and the introduction of feasible external resources. This focus can be seen in every process, from the conception of design principles to the design of building details and material choices. Integration and familiarization are also another key aspect of this thesis, which will improve its application and impact in the context of Thailand. Lastly, the evaluation process is conducted to guarantee that the compromises made in this thesis can still yield an acceptable outcome. In essence, this thesis intends to be a logical piece in a bigger picture of Thai sustainable construction industry development.

Even though, the end solution might not be the focus of this thesis, some of its aspect can be seen from the outcome of evaluation process. The result of evaluation has shown that local timber has the least carbon emitted of all the construction system. It only loses to imported timber when carbon sequestration is included to the calculation. If the sustainable source timber can be made available locally for Thai buildings, the benefit of carbon sequestration can be combined with its already low carbon emission. Enabling this source of local timber product can be achieved with the development of sustainable forestry along with wood-based material production and should be part of sustainable developments for built environment in Thailand.

Future research and projects

Aside from the establishment of "Thai contemporary timber construction system", this thesis has uncovered many potential research and projects that are related to the topic of contemporary construction in Thailand context. Due to its design nature, these future research and projects are identified from the process of development. Some of them are the knowledge which are relevant to this thesis, but cannot be pursue from the lack of resources and time constraints. Some others are alternatives project that has been decided not to focus on.

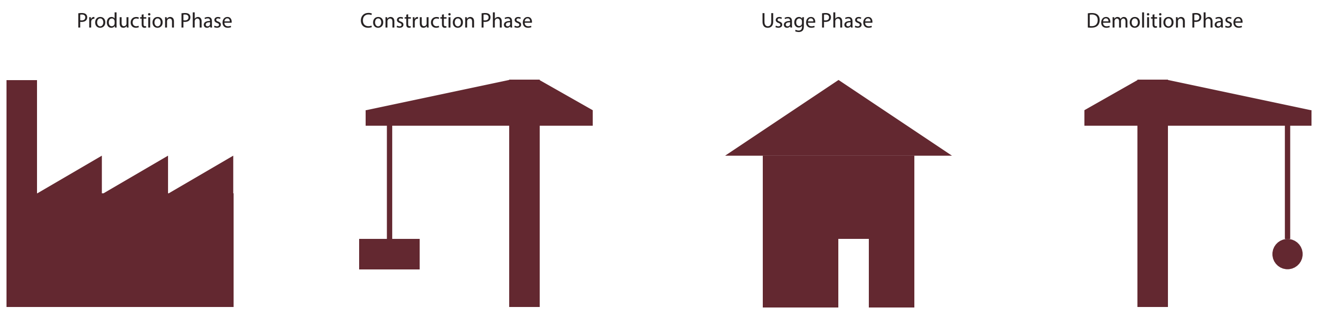
fig 91. Land in Thailand - photo : Viriyaroj B.

Complementary research

One important topic is the comparison of climate control and building energy consumption for air conditioner between concrete building and timber building. Materials use in each building has significant effect on its ability to maintain comfortable indoor temperature. For the residential building in warmer climate, enveloping element with low mass has an advantage over more massive material. Thermally massive material can delay the transmission of heat from the environment to the indoor space. The delay causes the stored heat to be transmitted after several of hours of heat exposure. This mean that, the interior of thermally massive material buildings will have higher temperature during night time. In the buildings with less daytime occupation, such as residential buildings, using material with lower mass will consume less energy from air condition than a more massive material[7]. Therefore, utilization of lower mass material like wood has the potential to reduce household energy consumption. This concept can be research and developed further, and can resulted in an enveloping system that fit with Thai climate and the user's behavior.

In this thesis the evaluation process only accounted for architectural and structural elements, in order to streamline the process and significantly reduce the workload from building design and material calculation. However, this does not mean that the full Life Cycle Assessment (LCA) for CO_2 emission and construction cost is irrelevant to the development of sustainable timber construction in Thailand. A more precise outcome of full LCA, can give a much more realistic picture. In the context of introducing a new construction system, precise evaluation is invaluable to the realization of an actual project. Aside from the clear benefit in environmental topic, this extended assessment can also help persuade the clients to choose timber construction. Initial construction cost is the deciding factor for the client's decision and it is the aspect that current timber construction cannot compete with concrete construction. However, timber construction has other financial advantage that cannot be initially perceive without a deeper examination. In the previous paragraph, it has been mentioned that timber construction has a potential to perform better in the topic of energy consumption, which can result in less household energy expenses for the house owner. End of life opportunity is also another aspect that timber construction performs financially well in the context of Thailand. Reuse and recycle of wood are an established practice in Thailand and it is not difficult to find a market for second-hand timber. This means that, some of the higher investment in to the house can be returned to the owner once the building has reached its end of life. The comparison between timber building and concrete building in the topic of energy consumption and end of life opportunity can be explored through full LCA and can potentially be the next step of this thesis

Another research that can compliment this thesis is behavior of wood-based construction material in the climate of Thailand. Currently, the research in this topic lacks a holistic approach that include aspects in building design, industrialized wood-based material and foreign species of wood. This is the knowledge that has been missing in the development of "Thai contemporary timber construction system". A proper research in this topic can help timber building to withstand the threats that are local to this climate type. This will result in a more durable and efficient construction, which can certainly benefit this thesis or any other future timber construction project in Thailand.



7. CHIRARATANANON, S. and HIEN, V.D. (2011). Thermal performance and cost effectiveness of massive walls under Thai climate. Energy & Buildings, 43(7), pp. 1655-1662.

fig 92. Other building type for timber construction


fig 93. Thai vernacular architecture

Alternative projects

Apart from the three future research that can directly improve this thesis or its continuation, there are other relevant topics that are has not been focused on. The process of choosing the building types for "Thai contemporary timber construction system" is rather simple and the decision is based only on the logic of potential audiences' number. Choosing a suitable building type for contemporary timber construction in Thailand can be explore as a research topic, which can contribute to the development of Thai timber construction and can also complement "Thai contemporary timber construction system" project.

Not only contemporary architecture can take advantage of this thesis, it can benefit vernacular architecture as well. The application of softwood timber from renewable sources in Thai vernacular architecture is another interesting project. These renewable sources can be used to overcome the challenge of material scarcity for "Ruen Thai". The project can be focus on softwood behavior in Thai climate, application of industrialize products and wood working joineries of Thai vernacular architecture.

These are the potential research and projects that has been identified during the process of thesis development, and many more can be discovered with further examination. These potential possibilities are essential for the development of Thai sustainable construction industry. Through the development "Thai contemporary timber construction system" and the discovery of potential research, this thesis has more or less contribute to the development of a more sustainable form of construction in Thailand and has created a positive impact to the overall sustainable development.

fig 92. Other building type for timber construction - source : http://navi.finnisharchitecture.fi/tuupala-timber-school/
fig 93. Thai vernacular architecture - source : https://www.muangboranmuseum.com/landmark/the-thai-hamlet-from-the-central-plains/

fig 94. Timber Architecture in Thailand

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References

1. En.wikipedia.org. (2018). List of countries by cement production. [online] Available at: https://en.wikipedia.org/wiki/List_of_countries_by_cement_production [Accessed 15 Mar. 2018].
2. Siammasterwood.com. (2019). ไม้เต็ง. [online] Available at: http://www.siammasterwood.com/ไม้เต็ง.html [Accessed 27 Aug. 2019].
3. Weatherbase. (2019). Bangkok, Thailand Köppen Climate Classification (Weatherbase). [online] Available at: https://www.weatherbase.com/weather/weather-summary.php3?s=55484&cityname=Bangkok,+Thailand [Accessed 27 Aug. 2019].
4. Thai Meteorological Department. (2018). Available at: https://www.tmd.go.th/info/info.php?FileID=56 [Accessed 21 Oct. 2018].
5. Stat.dopa.go.th. (2018). [online] Available at: http://stat.dopa.go.th/stat/statnew/upstat_age_disp.php [Accessed 21 Oct. 2018].
6. Worldpopulationreview.com. (2018). [online] Available at: http://worldpopulationreview.com/world-cities/bangkok-population/ [Accessed 21 Oct. 2018].
7. CHIRARATANANON, S. and HIEN, V.D. (2011). Thermal performance and cost effectiveness of massive walls under Thai climate. Energy & Buildings, 43(7), pp. 1655-1662.
8. Windfinder.com. (2019). Windfinder.com - Wind and weather statistic Bangkok Pilot. [online] Available at: https://www.windfinder.com/windstatistics/bangkok_pilot [Accessed 27 Aug. 2019].
9. Sunearthtools.com. (2019). Calculation of sun's position in the sky for each location on the earth at any time of day [en]. [online] Available at: https://www.sunearthtools.com/dp/tools/pos_sun.php?lang=en [Accessed 27 Aug. 2019].
10. Statbbi.nso.go.th. (2018). [online] Available at: http://statbbi.nso.go.th/staticreport/page/sector/th/01.aspx [Accessed 21 Oct. 2018].
11. En.wikipedia.org. (2019). Formosan subterranean termite. [online] Available at: https://en.wikipedia.org/wiki/Formosan_subterranean_termite [Accessed 27 Aug. 2019].
12. COFFMAN, B.E. (2004). THE POWER OF RISK: POETICS OF STANDARDIZED WOOD CONSTRUCTION, University of Cincinnati.
13. LENNARTZ, WILHELM, M., and JACOB-FREITAG, S. (2015). New Architecture in Wood : Forms and Structures
14. KOPPELHUBER, J., BAUER, B., WALL, J. and HECK, D. (2017). Industrialized Timber Building Systems for an Increased Market Share – a Holistic Approach Targeting Construction Management and Building Economics.
15. TANTASAVASDI, C., JAREEMIT, D., SUWANCHAISKUL, A. and NAKLADA, T. (2007). Evaluation and Design of Natural Ventilation for Houses in Thailand, Journal of Architectural/Planning Research and Studies Volume 5. Issue 1.
16. HUGHES, T., STEIGER, L. and WEBER, J. (2007). Timber Construction
17. KOLB, J. (2008). Systems in Timber Engineering
18. HERZOG, T., NATTERER, J., SCHWEITZER, R., et al. (2012). Timber Construction Manual.
19. Antti Ruuska. (2013) Carbon footprint for building products ECO2 data for materials and products with the focus on wooden building products. VTT Technology 115. 126 p. + app. 2 p.
20. Prof. Geo7 Hammond & Craig Jones. (2011) Inventory of Carbon & Energy (ICE) Version 2.0
21. the Guardian. (2019). Toxic smog forces Bangkok to close hundreds of schools. [online] Available at: https://www.theguardian.com/world/2019/jan/30/toxic-smog-forces-bangkok-to-close-hundreds-of-schools [Accessed 27 Aug. 2019].
22. Freightos. (2019). Ocean and Sea Freight Rates | Container Shipping Rates | Freightos. [online] Available at: https://www.freightos.com/freight-resources/ocean-freight-explained/ [Accessed 27 Aug. 2019].
23. Ecta.com. (2019). [online] Available at: https://www.ecta.com/resources/Documents/Best%20Practices%20Guidelines/guideline_for_measuring_and_managing_co2.pdf [Accessed 27 Aug. 2019].
24. Meyer-Veltrup, Linda & Brischke, Christian. (2015). Fungal decay at different moisture levels of selected European-grown wood species. International Biodeterioration & Biodegradation. 103. 23-29. 10.1016/j.ibiod.2015.04.009.
25. VIITANEN, H.A. (1997). Modelling the Time Factor in the Development of Brown Rot Decay in Pine and Spruce Sapwood - The Effect of Critical Humidity and Temperature Conditions. Holzforschung, 51(2), pp. 99-106
26. MA, X., JIANG, M., WU, Y. and WANG, P. (2013). Effect of Wood Surface Treatment on Fungal Decay and Termite Resistance. BioResources, 8(2),
27. GHALY, (2011). Termite Damage to Buildings: Nature of Attacks and Preventive Construction Methods. American Journal of Engineering and Applied Sciences, 4(2), pp. 187-200.
28. PALMQUIST, K., SALATAS, J. and FAIRBROTHER, A. (2012). Pyrethroid Insecticides: Use, Environmental Fate, and Ecotoxicology. InTech
29. กรมศิลปากร. (2010). โครงการจัดทำองค์ความรู้ด้านการสำรวจสถาปัตยกรรมเพื่อการอนุรักษ์โบราณสถาน (อาคารเรือนทรงไทย)
30. RAMASOOT, S. (2013). Sustainability via Adaptability: Learning from the Traditional Thai House's Built-for-Change Architecture.
31. SUTTANAN, N. (2015). The Space under stilt houses in a Thai Social Context: The Transformation to a Main Functional Space
32. Thailand.unfpa.org. (2018). [online] Available at: https://thailand.unfpa.org/sites/default/files/pub-pdf/State%20of%20Thailand%20Population%20report%202015-Thai%20Family_th.pdf [Accessed 21 Oct. 2018].
33. LSTIBUREK, J. (2002). Moisture Control for Buildings
34. PICHETSILPA, K. (2002). A Guideline for building wall system to improve thermal performance.
35. Woodproducts.fi. (2019). [online] Available at: https://www.woodproducts.fi/sites/default/files/a_buyers_guide_to_wood_products_2018_0.pdf [Accessed 27 Aug. 2019].

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fig 24., fig 25., fig 26., fig 27., fig 28., fig 29. กรมศิลปากร. (2010). โครงการจัดทำองค์ความรู้ด้านการสำรวจสถาปัตยกรรมเพื่อการอนุรักษ์โบราณสถาน (อาคารเรือนทรงไทย)
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fig 66. source : https://dsignsomething.com/2018/06/07/บ้านสวย-ที่เลือกปิดและเ/
fig 67. source : https://dsignsomething.com/2018/03/29/พักใจที่บ้านแห่งความสม/
fig 68. source : https://dsignsomething.com/2017/12/28/โฮมบุญ-บ้านที่เกิดจากวิ/
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fig 79. Row-blocks - source: https://th.wikipedia.org/wiki/ไฟล์:ตึกแถวแพร่งภูธร188.jpg
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fig 81. adapted from - https://www.thaitravelblogs.com/2011/10/map-of-flood-risk-areas-in-bangkok/
fig 82. adapted from - http://www.gregtodiffer.com/the-future-of-bangkoks-mass-transit/
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fig 84. Thai Local Timber - source: Viriyaroj B.
fig 85. Production Phase - source : http://hawkinssawmill.com/north-central-mn-sawmill-about-hawkins-sawmill/
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